insights and recommendations from the maa national study of college calculus

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Chapter 8

Beyond Good Teaching

The Benefits and Challenges of Implementing Ambitious Teaching

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Ambitious Teaching is the label Sadler and Sonnert attached to a collection of instructor characteristics addressed in the CSPCC survey (see Chapter 2). These characteristics include the use of group projects, the inclusion of unfamiliar problems both in homework and on exams, requirements for students to explain how they arrived at their answers, and a decreased reliance on lecture as the primary mode of instruction. A factor analysis revealed these to be highly correlated and independent of a second group of instructor characteristics that were labeled as Good Teaching (Chapter 7). Note that characteristics included in the ambitious teaching factor are consistent with instruction that is often referred to as *active learning* or *student-centered instruction*.

Lampert, Beasley, Ghousseini, Kazemi, & Franke (2010) define ambitious teaching as teaching designed to meet the ambitious learning goal of developing conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive dispositions proposed in the National Research Council's *Adding it Up* (Kilpatrick, Swafford, & Findell, 2001). Lampert and colleagues argue that this kind of teaching necessarily involves actively engaging students by having them share and refine their reasoning through interaction with their instructor and classmates. In this chapter we will use the term ambitious teaching in two ways. When we discuss the CSPCC survey results, we use this term in the same way as Sadler and Sonnert defined it in Chapter 2, in reference to their factor analysis of the survey. All other uses of the term ambitious teaching should be understood to be a reference to instructional approaches consistent with Lampert et al.'s notion of ambitious teaching. While these two uses of this term are not identical, the characteristics of the label as used by Sadler and Sonnert are broadly consistent with Lampert et al.'s construct so that there should be no confusion.

Analyses of the survey data indicate that lecture continues to be the predominant mode of instruction in Calculus I across the country. This is true despite the fact that better approaches to teaching and learning are well documented. Based on their meta-analysis of 225 studies, Freeman et al. (2014) argued that active learning has been empirically validated as a preferred approach to teaching. Student-centered instruction has been shown to support conceptual learning gains (e.g., Kogan & Laursen, 2013; Kwon, Rasmussen, & Allen, 2005; Larsen, Johnson, & Bartlo, 2013), diminish the achievement gap (Kogan & Laursen, 2013; Riordan & Noyce, 2001; Tarr et al., 2008), and improve STEM retention rates (Hutcheson, Pampaka, & Williams, 2011; Rasmussen, Ellis, & Bressoud, 2014; Seymour & Hewitt, 1997).

The purpose of this chapter is to provide a pragmatic discussion about ambitious teaching. Drawing on the research literature and the CSPCC project, we will discuss the potential benefits of incorporating aspects of ambitious teaching in Calculus I instruction and the challenges related to successfully implementing and sustaining such ambitious teaching practices.

We will start by summarizing some relevant results from the CSPCC national survey. First we will characterize the extent to which students (from both the national sample and the schools selected as case study institutions) reported experiencing ambitious teaching practices. Then we will summarize the findings from two studies that examined connections between ambitious teaching practices and outcomes. One of these studies examined connections between ambitious teaching and changes in student attitudes and beliefs, while the other examined connections between ambitious teaching and students' intentions to continue on to Calculus II.

These findings are mixed and we will devote a section to understanding the findings. This discussion will motivate a brief review of the educational research literature, which will focus both on the reported benefits of ambitious teaching and findings related to the challenges involved in implementing and sustaining such practices.

We will then turn our attention back to the CSPCC project and discuss what we have learned from our case studies regarding ambitious teaching. Specifically, we will present in some detail two important examples of ambitious teaching that emerged from our case study research. First we will discuss a long running program of ambitious Calculus I instruction that dates back to the calculus reform movement of the 1990s. Then we will discuss an ongoing project to innovate Calculus I instruction to including technology-supported ambitious teaching.

Results From The CSPCC National Survey

The CSPCC national surveys included questions about what kinds of instruction students received. It also included questions designed to track changes in students' intention to take Calculus II, and changes in their confidence in mathematics, enjoyment of mathematics, and interest in mathematics (see Appendix A). This section will describe two independent studies using the CSPCC survey data to examine relationships between ambitious teaching and outcomes (retention and changes in attitudes and beliefs). First we will present a basic analysis of the survey data that characterizes the extent to which students reported ambitious teaching both nationally and at the selected case study institutions.

Characterizing the extent to which students reported ambitious teaching

At the end of their Calculus I course, students from the sampled institutions were asked to rank the frequency of various pedagogical activities. Over 5,500 students completed end of term surveys (see Hsu, Mesa, & The Calculus Case Collective, 2014). Students at selected and non-selected institutions reported that lecturing was frequently occurring in their classes, with *Very Often* as the most popular response. In fact, as we see in Figure 1, the percentage of students selecting a response strictly increases as responses choices move from *Not at All* to *Very Often*. This trend was consistent both nationally and at selected schools.

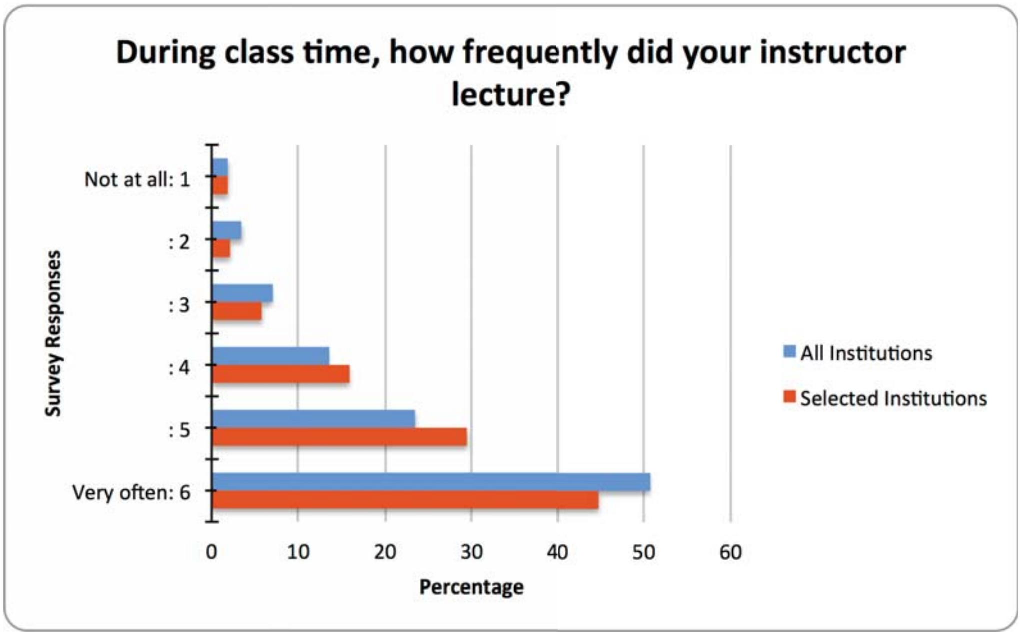

Figure 1: Percentage of students reporting levels of lecture frequency at all institutions (N = 5,565) and at selected institutions (N = 1,221).

Questions about activities associated with ambitious teaching revealed a different pattern of responses. Figure 2 reflects students' responses on the frequency of working with other students during class time. *Not at all* was the most common response nationally (29%); however, high frequencies (5 and 6) were the next most reported options. At selected institutions (N = 1,220), only 19% of students selected *not at all.* This proportion was significantly ($z = 9.36$, $p < .01$) smaller than the proportion (33%) of students selecting *not at all* from non-selected institutions (N = 4,338).

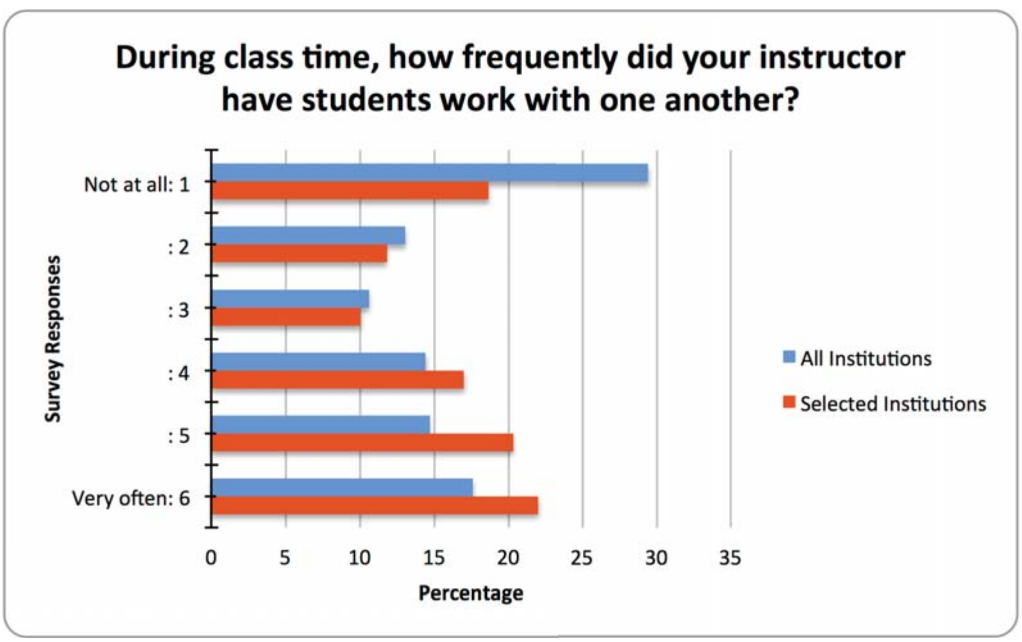

Figure 2: Percentage of students reporting levels of collaborative work frequency at all institutions (N = 5,558) and at selected institutions (N = 1,220).

The frequency of student responses was similar for three other ambitious teaching activities, class time spent on working individually on problems, asking students to explain their thinking, and whole-class discussion, for the selected institutions and all the institutions in the sample. In all cases, the selected schools typically had a higher percentage of students selecting *Frequently or Very Often* and fewer students selecting *Not at All or Not very Often* (see Table 1).

Table 1: Percentage of reported class time spent on ambitious teaching activities for selected institutions (N = 1,221) and all institutions (N = 5,554).

	Not at All or Not very Often		*Frequently or Very Often*	
	Selected Institutions	All Institutions	Selected Institutions	All Institutions
Work individually on problems or tasks	17%	26%	45%	39%
Explain thinking	19%	26%	44%	40%
Whole-class discussion	32%	37%	36%	34%

Note: The students were asked to rate the frequency of the activities on a 6-point Likert scale, (1: *Not at All* through 6: *Very Often*)

While lecture was prevalent at both selected and non-selected institutions, the comparison of ambitious teaching activities suggests that calculus programs at selected institutions tend to have instructors integrating ambitious teaching to a higher degree than in the rest of the institutions in our sample. These results may also suggest that integrating some ambitious practices even while using a significant amount of lecturing, might be a good move for any.

Ambitious Teaching: Changes in Attitudes and Beliefs and Intention to Switch Out

Sonnert and Sadler's analysis of our survey data (see Chapter 2) revealed that good teaching (see Chapter 7) had a positive impact on the composite of change in student attitudes (confidence, enjoyment and desire to take more mathematics) and that ambitious teaching had a small negative impact on that composite.

Rasmussen and Ellis (2013) pursued a complementary analysis to identify the characteristics of students who indicated an intention to take Calculus II at the start of the term, but who changed their intention at the end of Calculus I (called *switchers*) or maintained their intention to continue on to Calculus II (called *persisters*). Their analysis considered the connections between good teaching and ambitious teaching and the students' decision to switch or persist. They found that ambitious teaching practices were associated with lower switcher rates. More specifically, when high levels of ambitious teaching were coupled with low levels of good teaching, only 12% of students switched (compared to the 14% overall national percentage of students who switched). And when high levels of ambitious teaching were coupled with high levels of Good Teaching, just 7% of students switched. These findings suggest that there is some promise in using a combination of good teaching and ambitious teaching if the goal of improving student attitudes and beliefs and student persistence.

Ambitious teaching by itself did not appear to be related to positive changes in the composite of student attitudes in the survey. As we detail in the following section, this finding is consistent with prior research. Educational research that attempts to relate ambitious teaching to changes in student attitudes and beliefs must overcome significant methodological challenges. In particular, it is extremely challenging to characterize attitudes and beliefs in useful ways and then develop valid measures that are aligned with these characterizations. In the case of the CSPCC survey, our measures of attitudes and beliefs are quite rough, incomplete (only confidence, interest, and enjoyment are included), and are self-reported. So it might be premature to assume that ambitious teaching has a negative impact on students' attitudes and beliefs, without considering other potential explanations.

It is also worth noting that the changes in student attitudes and beliefs that were studied in the CSPCC survey only partially address changes in students' productive disposition, one of the five strands of mathematical proficiency described by NRC's *Adding It Up* (2001). Ambitious teaching is meant to support also conceptual understanding, procedural fluency, strategic competence, and adaptive reasoning (NRC, 2001). Our inconclusive findings may suggest that implementing ambitious pedagogies successfully is challenging. In the remainder of this chapter, we will draw on the research literature and use the CSPCC case studies to discuss the potential benefits of ambitious teaching, the challenges of implementing it, and the factors that can support overcoming these challenges.

What Does The Research Literature Say About Ambitious Teaching?

As indicated by the meta-analysis reported by Freeman et al. (2014), the research literature supports the idea that ambitious teaching can have significant benefits in terms of student learning. The literature suggests that there is a complex relationship between ambitious teaching and non-cognitive outcome variables. In this section, we will briefly review the research literature regarding ambitious teaching. First, we will discuss the potential benefits reported in the literature. Then we will consider some of the challenges involved in realizing these benefits. Finally, we will consider what kinds of things support implementing and sustaining ambitious teaching practices.

Lampert et al. (2010) argue that ambitious teaching necessarily involves actively engaging students by having them share and refine their reasoning through interaction with their instructor and classmates. Freeman et al. (2014) suggest that it is possible to see benefits with a variety of types and levels of ambitious teaching. A meta-analysis of 39 studies in multiple STEM fields found that small-group learning had a positive impact on achievement, persistence, and student attitudes (Springer, Stanne, & Donovan, 1999). More specific to calculus, a number of studies have examined the impact of the “reform calculus” that emerged in the 1990s, which emphasized conceptual understanding and applications, often with the use of technology to facilitate this focus. These studies have consistently found that students from reform courses developed stronger conceptual understanding and were more likely to persist in STEM fields while showing little or no negative impact on procedural fluency (Chappell & Killpatrick, 2003; Hurly, Koehn, & Ganter, 1999; Joiner, Malone, & Haimes, 2002).

The literature is less clear regarding connections between ambitious teaching and non-cognitive outcomes (including attitudes and beliefs). Smith & Star’s (2007) review of the literature noted that studies tended to focus on achievement, with studies focused on non-cognitive outcomes being less common and less carefully conducted. In particular, they noted that researchers do not define carefully terms such as “beliefs,” “attitudes,” and “perceptions;” and the findings from these studies are mixed. For example, consider two studies focused on reform calculus. On the one hand, Bookman and Friedman (1998) found that early in their experience with reform calculus, students disliked it, but that one and two years after their reform calculus experience these same students more strongly felt that they understood how mathematics was used compared to students who were taught in the non-reformed courses. On the other hand, Brown (2000) found that students’ reaction to the Harvard Consortium Calculus became more negative when the program was scaled up to all sections. One promising (and more well-defined) finding is Hofer’s (1999), who found that reform calculus students had more sophisticated beliefs about mathematics than students taught in the non-reformed courses. In their own study, focused on transitions in which students experienced changes in their educational experiences, Smith & Star (2007) found that the transition from high school to college had a large impact on student achievement (in terms of grades) while transitions from reform to traditional instruction (or vice versa) did not. They also examined interaction between achievement and students’ dispositions. They reported that “achievement and disposition were positively related dimensions of students’ mathematical experience (at least as they move between traditional and reform programs), but that relationship was modest in strength and defied simple or uniform description” (p. 28). Smith & Star argued for a more sophisticated conceptualization of outcomes that recognizes that students who experience similar changes in achievement (e.g., a drop in test performance) may react in a variety of ways affectively.

The complexity inherent in students’ reaction to ambitious teaching is likely one of the things that makes it challenging to implement and sustain a transition to ambitious pedagogical practices. However, the challenges a teacher engaged in ambitious teaching will encounter go beyond dealing with possible pushback or other negative reactions on the part of students. A hallmark of ambitious teaching is engaging students with cognitively demanding tasks, and the research suggests that the teacher has an important role in keeping students engaged at a high level. For instance, Henningsen & Stein (1997) identified a number of teacher behaviors that supported high levels of student mathematical engagement including scaffolding, modeling high-level performance, and consistently pressing students to provide meaningful explanations.

The significant effort needed to successfully engage in ambitious teaching is not the only factor that can inhibit reform initiatives. Woodbury & Gess-Newsome (2002) found that teachers' perceptions of the necessity for change had a significant impact on their responses to messages about reform initiatives. If teachers were not dissatisfied with the current instructional approach, they were unlikely to embrace changes. In addition to this critical factor, five other factors were identified as influencing teachers' reaction to, and enactment of, change. These were, "(a) a departmental culture of sharing, (b) teachers' sense of autonomy, (c) teachers' professional development experiences, (d) the nature of reform messages and messengers, and (e) teachers' views of themselves in relation to the reform movement" (p. 777). Of course initiating a transition to ambitious teaching is only a beginning. Sustaining such a change presents its own challenges. Coburn, Russell, Kaufman, & Stein (2012) note that sustaining innovations in instruction requires teachers (and others) to make continual adjustments to new conditions. They found "that teachers with a solid grasp of reform-related instructional strategies are able make adjustments that maintain high-quality instruction," (p. 165). Further they found that sustainability was supported by social networks that were characterized by strong ties, in-depth interaction, and high levels of expertise.

In summary, the research literature supports the notion that ambitious teaching can have important benefits for students in terms of their conceptual understanding without hindering their procedural understanding. While the literature does include some positive findings relating ambitious teaching and student attitudes, the impact of ambitious teaching on non-cognitive outcomes is a complex issue that requires more study. The role of the teacher is of course central. Engaging in ambitious teaching is a challenging endeavor for any instructor and faculty are unlikely to embrace such a challenge if they are satisfied with their current teaching. Finally, the sustainability of shifts to ambitious teaching depends upon the existence sufficient supports for teachers.

Ambitious Teaching in the CSPCC Case Studies

The research literature suggests that ambitious teaching can have important benefits. The literature also makes it clear that ambitious teaching can be challenging to implement and sustain. In this section, we examine the two most robust examples of large-scale ambitious teaching that we encountered in our case study site visits. The first is an established program that has been ongoing for two decades and the second is a newer initiative, but one that continues a tradition of technology-related instructional innovation at the institution. We begin each subsection with a brief overview of each calculus program and an explanation of why we consider it to exemplify ambitious teaching. These descriptions will be followed by a discussion of how these aspects are viewed by the participants in the program. This discussion will include the perceived benefits and challenges of engaging in these practices, as well as insights into what characteristics of the institution and calculus program support the success of these ambitious pedagogical practices.

Sustained Ambitious Teaching: The Case of Large Public University 1

Large Public University 1 (LPU1) is a large public institution serving more than 44,000 students with 26,000 full-time undergraduate students. At the time of the interviews, 53 sections of Calculus I were taught in the fall by 48 instructors, who were mostly graduate students. The current approach to Calculus I at LPU1 can be traced back to the early 1990s reform movement. For more than two decades, the department has been focusing on conceptual understanding and student engagement. Calculus I is taught in small sections (of approximately 32 students) using the Harvard Consortium Calculus text (Hughes-Hallet, 2012). The graduate students who teach calculus are called Graduate Student Instructors (GSIs) and have autonomy over their in-class instruction, but are encouraged to feature small-group work. All students take common midterms and a common final. Homework is also common, with students doing online homework that is procedurally focused and team homework problems that are conceptually focused. The GSIs participate in a robust training program that includes instruction in the ambitious teaching practices that characterize the program. Training is used to explain the benefits of the ambitious practices and to provide practical instruction in implementing them. Each semester, one of the GSIs helps to coordinate the course. This GSI coordinator is responsible for writing some of the team homework problems and conducting classroom observations of new GSIs.

How is the teaching ambitious? The Calculus I program at LPU1 includes a number of ambitious pedagogical practices that are consistent with the aims of the Harvard Consortium text used by all instructors. There is an emphasis on having students routinely explain their thinking: they provide extensive explanations on team homework assignments and brief explanations regularly on conceptually focused exams. In addition to the collaboration on team homework problems, students worked in small groups during class time (with the amount of time devoted to group work varying by instructor).

What do the participants have to say about these ambitious pedagogical practices? One of the things that stood out from our site visit to LPU1 is how consistent the various participants were in identifying the primary characteristics of the Calculus I program. Administrators, instructors, and students all described group work, an emphasis on conceptual understanding, and a consistent requirement for students to explain mathematics and their own thinking. For example, in the following interview response, we see the GSI coordinator describe the emphasis on applications and the insistence on having students write explanations:

> *They're problems that involve explaining, a lot of explaining. So... they'll be something like, "Oh this weird phenomenon happened." "Why is this going on?" or something like, "Your friend tells you that this can't possibly be right because of this, why is your friend wrong?"... So there are a lot of things where it's checking that they're really understanding. Making them explain things really thoroughly.*

Thus, the team homework problems presented students with a real world situation and asked them to discuss its relevant mathematical aspects. They were required to use calculus concepts to address the problems and provide detailed explanations to go along with the procedures they used to solve the problem. Such problems serve to connect the mathematics to areas of interest to students in applied disciplines like engineering, and also provide a way to assess students' understanding of the concepts rather than merely their ability to select and execute procedures. In the following two quotes, we see students at LPU1 confirming the emphasis on applications and on writing explanations:

> *It's not just memorizing the formulas. It's mostly applying them. It's difficult to do. In my high school we didn't, it was just like memorizing and applying. Here it's much more different.*

> *Being the person who actually has to write the explanation stuff, it's a total pain, but I understand why they're trying to make you do it because they want you to really understand it.*

Both comments evidence the students' perception that these aspects of the course make it more challenging and time-consuming. The students consistently felt that their calculus course was more challenging than their high school calculus course or the college calculus courses their friends were taking at other institutions:

> *I have friends who are taking Calc I at other colleges and they show me like the hardest problem on their test and I'm like, really? Like that's not even close to any of the problems that we ever have to do. It's so easy.*

The participants we interviewed were also consistently positive about the Calculus I program and its benefits. There was a near consensus that the program was well suited for developing strong conceptual understanding of calculus and for preparing students to succeed in future science and engineering courses. The engineering advisor at the institution indicated that the conceptually focused curriculum was "a very good curriculum for training engineers" because it focused on "quantitative reasoning, understanding the concepts and not just knowing mechanics." The course coordinator pointed out that a major benefit was having "the opportunity to hear where they're confounded or confused or have a little misinterpretation or understanding." One of the students, referring to small group work, pointed out that it is mostly beneficial "because you get to see different students answer the problems in different ways, ways in which you are not used to. Different ways help you learn the problem better." So while there were aspects of the program that some participants had negative or mixed feelings about (students felt team homework required excessive explaining, the administration desired greater participation from tenured faculty, and instructors expressed mixed feelings about group work during class), the participants were consistently of the opinion that the methods used by the program were effective. The following quote from a GSI offers some clues why the program continues to be successful and to be perceived as successful by the participants:

> *We go through a week of training before we become a GSI and it's stressed to us that this is sort of [LPU1] philosophy. This is how we've run our course in the past, and it's been really successful, and it's a good idea to use this group work in your teaching. I think most people get sold on it, and they don't really question it because it does really seem like it's really effective.*

This comment alludes to both the success of the program's training component and the fact that the program enjoys established stability and a documented record of success. In the following section, we will argue that these factors go a long way toward explaining the ongoing success of the program in sustaining ambitious teaching practices.

What is supporting or constraining these ambitious pedagogical practices? This case is particularly important and interesting because some rather ambitious practices have been institutionalized and the program has resisted a number of challenges over the years.

Challenges from the institution's administration have focused on the cost of the small sections. Multiple participants (e.g., GSIs, instructors, and the department chair) argued that the small class sizes were absolutely essential. The associate chair was teaching a large lecture section of pre-calculus at the time we interviewed him. He noted that, "I barely know any of them. I can't tell you anything about their intellectual capabilities unless I have the person and the spreadsheet and ...That's not how it's supposed to be."

Nevertheless, the program has sustained ambitious teaching practices for over two decades. Based on our interviews, we identified a number of factors that may explain this sustained success. Perhaps the most important one is that the faculty took steps to use locally collected data to assess the success of the program and that the data documented success in supporting students' development of conceptual understanding of calculus.

The success of ambitious teaching of a course depends primarily on the instructor. In this case, the instructors are almost exclusively graduate student instructors, many in their first year of graduate school. The GSI trainer and the department chair both noted that the graduate students' teaching evaluations are at least as good as those of senior faculty members. Although this might be explained because students might relate better to GSIs who are closer to their own ages, the students of these GSIs were just as successful in demonstrating conceptual understanding as measured by the Calculus Concept Inventory (CCI, Epstein, 2007) as the faculty teaching the course. The former course coordinator, who used the CCI to evaluate the calculus program in the face of challenges from administrators said,

> *I was scared spitless. I really was. You know, what if we fall on our face? I mean, we'll find out something we don't want to know, but I thought, well I don't know what else to do right now.*

In fact, the results were strikingly positive, and she noted that one of the findings was the that "the new guys, the brand new grad students, did just as well as the more experienced."

The success of the graduate students is likely due in part to the GSI training, which appears to be successful both in terms of articulating the key characteristics of the program (so that the GSIs know what it is they are supposed to do in their classrooms) and selling these characteristics as essential. This job of selling the program is of course made easier by the fact that the GSI trainer (and other mentors) can point to the study using the CCI to argue that the program does indeed support students' conceptual understanding. This success is also helpful in defending the program against pushback on the part of students and administrators alike. The former course coordinator was clearly aware of the need to convince the students of the benefits of the program and that in order to do this, she needed to "sell it to our instructors first … And if they believe in it you'll find many fewer complaints [from the students]."

As the GSI quotes suggest, the trainer has been successful in selling the program to the instructors; likewise, our interviews with students suggest that the students are convinced of the quality of the program as well and that they realize that they are taking a challenging calculus course.

Takeaways from the case of ambitious teaching. It should be noted that a department wishing to build a program similar to the one detailed will need to consider that the LPU1 program has been in place for over two decades. In its current state, the program enjoys much of the same inertia that is typical of traditional programs. At this institution, ambitious teaching is now normative and new teachers are expected to engage in these practices because that is how Calculus I is done there. However, considering the program in light of the research literature, there are some actions that could be taken by any department interested in establishing a similarly ambitious approach.

First, the program needs to set up a structure that would support ambitious practices—small classes with instructors who felt ownership of their classrooms. The associate chair argued that it was important for graduate students to teach their own classes rather than serve as recitation leaders saying, "I think when you give a teacher their own class and they're responsible for making sure they learn enough to actually pass the darn exam it changes the game a lot."

Second, the department needs to take steps locally to assess and document the existence of the kinds of increases in conceptual understanding that the research literature has linked to ambitious teaching. This documentation of success provided leverage to acculturate new instructors and resist pushback from students and administrators alike.

Third, the department will need to institute a robust training program for all instructors that sells the program to the instructors, makes the expectations clear, and supports the instructors in meeting those expectations, for the whole time they teach the course. Chapter 10 discusses in details the features of the GTA training program used in LPU1.

Technology-Supported Ambitious Teaching: The Case of Private Bachelors Granting University

Private Bachelors-Granting University (BA1) is a private university serving approximately 8,000 students on a large campus situated in a suburban area. There are 12 tenured or tenure track faculty in the mathematics department who typically teach three or four classes per term. BA1 has a long history of testing and adopting innovative teaching practices with strong support from the department chair and deans. The current department chair's belief is that, "If somebody's got an interesting idea, we can find some money and let them try their interesting idea."[1] When the CSPCC project team conducted the case study visit, half of the calculus sections were being "flipped." This means students were required to watch lecture videos outside of class and then spend their class time working on problems and discussing their solutions in small groups of two to four students. The department was moving towards flipping all of the Calculus I sections for subsequent terms. Instructors had control over how they ran their classes, but the course was coordinated and there was a common final exam. Additionally, some common questions were used on midterms to allow the department to assess the success of the flipping project. Except for one section, all Calculus I sections were taught by full-time tenure-track faculty. All Calculus I sections were capped at 30 students; the flipped classrooms were capped at 24. Two of the 10 instructors teaching the Calculus I courses at the time of our site visit were mathematics educators and one of them was spearheading the flipped calculus study. Technology-supported teaching included online video lectures and various types of technology used to give demonstrations (e.g., graphing calculators and Maple), quickly assess student understanding (clickers), or share student work with the class (iPads and AppleTVs).

How is the teaching ambitious? BA1 is a case of an institution and more specifically a department with a history of active involvement in technology-related instructional innovation. Much of this innovative work is used to support active learning including group work, student presentations, whole-class discussions, and challenging tasks.

What do the participants have to say about these ambitious pedagogical practices? The instructors we interviewed indicated that the goal of technology-supported innovation was to increase student engagement. One instructor stated that his "main purpose of doing a lot of technology now is to get students involved in class." By flipping the classroom so that students view the lectures outside of class, instructors gain time for group work during class. One of the benefits of this in-class work is that it provides an opportunity for instructors to interact with students and assess students' understanding of the mathematics. One instructor noted that this kind of instruction also helped students to assess their own understanding, saying that, "By having them do the work in class, with their peers and with my support as needed, they get a real chance to test their understanding of the material that they've watched on the video or read in the book."

1 At the time of our data collection this institution, like many others across the country, was dealing with a severe budget shortfall.

Instructors at BA1 also increase student engagement by using iPads to project student solutions during whole-class discussions. A student noted that, "interacting with other students … you get everyone's idea and then you kind of form your own and develop it." This student's instructor (in a separate interview) made a similar point stating that giving students a chance to present their work allows them to, "clarify their thinking, sharpen their thinking, and communicate their thinking in a way that makes sense to a group of people. So I think that also helps deepen their understanding."

The technology-supported innovation at BA1 is also used to facilitate engagement in challenging tasks, including application problems, in order to deepen students' conceptual understanding. One instructor observed that moving the exposition about definitions and procedures to the online videos freed up time in class to get students "to think more deeply about problems, make connections, think in a more abstract way and solve more complex problems." These problems include application problems, which the dean of engineering observed to be a strength of the calculus program saying, "I think its strength is the application. That's the way we look at it from engineering. There are lots of examples done in the classroom to link concepts to what the students do." The calculus students also noticed this emphasis on conceptual understanding. When a group of students were asked how their instructor engaged with their small groups, they reported that their teacher did not often answer their questions directly but rather replied with questions, "so you have a deeper understanding of the concept that you're doing."

Of course, there were students and instructors alike who expressed slightly negative reactions to some of the technology-supported ambitious teaching at BA1. For example, some students expressed frustration with members of their small groups. While one student in a focus group interview reported that "I turned around to my partner and he basically helped me and from there I knew what I was doing," another said, "We sit there, we kind of look at each other and then we just do it on our own anyways." The dean of engineering related some mixed feedback he had received from engineering students about the flipped calculus initiative:

I heard from students about flipping the classroom... and they are very happy about it, they are really doing well and excited and whatever. I also heard from some that we should be [telling them] in advance that this is a flipped class because, as you know, some students learn by discovery, some students learn by imitation.

Overall, our interviews at BA1 revealed that the participants (students, instructors, and administrators) considered the Calculus I program to be quite successful. While some professors were hesitant to flip their own calculus sections before the evidence of impact had been established, the faculty was committed to exploring ways to increase student engagement.

What is supporting or constraining these ambitious pedagogical practices? The department chair noted the department had been, "refurbishing classrooms with tables, round tables, where the focus will be on students working in groups." This supported the instructors who wanted to have appropriately sized groups to use the technology in effective ways. One instructor noted that, "I think the calculus instructors kind of agree that two or three [students] seems to work best because … the students will be working over the iPads." Changing the layout of the classrooms was an important factor in supporting group work and using technology in the classroom. This was one way that the financial support provided by an internal grant was helpful in establishing the technology-supported innovation.

However, instructor buy-in is much more important to supporting and scaling up innovation than monetary support. The course coordinator noted that department-wide instructional changes were questioned before adoption. He noted that, "it's not that they're unwilling to make changes, but they have to be convinced and that's often not an easy thing to do." We saw evidence of this in two of our interviews with instructors. One instructor said, "I haven't decided yet on whether I want to make the investment to do that. I'd have to feel there was a payoff." Another instructor said,

If the department adapts [flipping], or adopts it as the mode of teaching here, it's something that I would pick up, but it's not where I come from. As to what I think, just maybe for lack of evidence, I haven't seen that it works better than what I'm doing.

As noted by Woodbury & Gess-Newsome (2002), the research literature reports that innovation depends on instructors seeing the need for change. The department at BA1 is collecting local data on student understanding (shared questions on midterms and common exams) in order to document whether the flipping initiative does indeed provide a better learning experience for students. In this way, the department is taking steps to answer skeptical instructors' reasonable questions about whether the change is worth the investment of time and energy. This important issue was not lost on the students either. For example, one student reported that students were avoiding an instructor's class because, "they had a teacher that was flipping, but didn't want to be."

We see this requirement of a perceived need for change in remarks of the department chair (also a Calculus I instructor at the time of the case study visit), who felt that something needed to be done with their calculus program, believing that all students in the class should be engaging with the mathematics:

> *The reason I wanted to flip was maybe part of the concerns. I felt like I could reach 75% of the class, but there was 25% of the class that were just sitting there, not responding to me, and could get by. They'd smile, they were happy, but they were not doing well in the course. I wanted to do something, and I thought we needed to do something, where we could get a little bit more interaction with everybody and make sure everybody's doing the work.*

Instructors who were dissatisfied with the level of student engagement during class initiated the flipped calculus innovation. However, there were also instructors that were satisfied with their instruction and were not sold on flipping. One of these instructors said, "there's always going to be compromise, but so far, every time we've done something that's common across the board, we've had discussions." This kind of collegial formal (and informal) communication was important for moving the innovation forward while ensuring that all of the faculty felt respected and included. That the department had a supportive faculty that shared ideas, were flexible, and were willing to communicate about instructional innovations enabled the department's tradition of technology-based instructional innovation. A number of instructors we interviewed spoke about the culture of the department and indicated its importance in supporting instructional innovation. One instructor noted that, "It's the collegiality. I think that's partially what makes it so successful, is that there are no real competing agendas here. And there's a lot of sharing of material and there's a sharing of ideas." This kind of culture also supports the constant refinement that the research literature suggests is necessary to sustain instructional innovations. The department chair said of the faculty,

> *It's a big part of their identity as a math department, that they are good successful undergraduate teachers, and that they're engaged in sort of tweaking and revising their teaching work over time to get better and better at it.*

Instructors at BA1 devote time to craft their instruction in order to best support students, in part by incorporating various technology-supported instructional innovations. This work is further supported by the university faculty development center. In interviews, instructors shared a common sentiment that learning new technologies was challenging, but was supported by the faculty development center. The dean of the College of Arts and Sciences noted that, "almost anything that goes on at the [faculty development center], the faculty that are in there teaching others are over-represented by mathematicians." The calculus instructors at BA1 were not simply consumers of professional development; they were leaders in sharing ideas about technology-supported instructional innovation.

Takeaways from this case of ambitious teaching. The largest contributing factor in the success of the calculus program at BA1 is the level of commitment to teaching by instructors and the department culture they create. Instructors were initially dissatisfied with the level of student engagement in Calculus I classes. This dissatisfaction motivated initiatives to innovate instruction (at an institution with a history of technology-supported instructional innovation) in order to increase student engagement. The department faculty see themselves as good undergraduate mathematics teachers and this identity motivated them to continually refine their instruction to produce high levels of engagement, incorporating ambitious teaching practices that include engaging students in group work, having students solve non-routine and application problems, and asking students to share and explain their thinking. The collegial nature of the mathematics department supports instructors both in spearheading innovation initiatives and in collecting local data to evaluate the impact of those initiatives (in order to provide colleagues with information needed to determine whether they should buy in). Finally, the mathematics faculty is able to get the most out of the institution's faculty development center by being active leaders in the center.

Discussion

The research literature and the results from the CSPCC project suggest that ambitious teaching practices are exactly that—ambitious. Teaching practices that move away from traditional lectures to incorporate active learning experiences (e.g., facilitating small-group collaboration, pressing students to explain their thinking, engaging students in solving non-routine problems, and conducting whole-class discussion) are ambitious in that they are meant to support lofty educational goals including the promotion of deep conceptual knowledge and active student engagement with mathematics as well as the development of sophisticated views about the nature of mathematics. They are also ambitious in the sense that they require substantial institutional supports and advanced knowledge, skills, and beliefs on the part of instructors. The benefits of such strategies can be significant, but institutions and instructors should be aware of the challenges of implementing such strategies and the conditions needed to address these challenges. The BA1 flipped calculus project and the LPU1 small-section active learning model are two examples of committed systemic efforts to incorporate ambitious teaching into calculus instruction. The BA1 flipped calculus initiative is a newer innovation, but one that continues a tradition of technology-supported efforts to increase students' engagement with mathematics. This case sheds light on what it takes to get a new innovation up and running at scale. The LPU1 program is a stable one that first emerged at the beginning of the 1990s calculus reform movement. It is a case that demonstrates that it is possible to institutionalize ambitious teaching in Calculus I. It is also a case that suggests programmatic practices that support and sustain a calculus program featuring ambitious teaching. These two cases and lessons from the literature provide a good foundation for any institution interested in revitalizing its own calculus program through the use of ambitious teaching practices.

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