

Foreword

COVID-19 has changed education forever. A sudden jolt required all classrooms to hastily dive into the virtual world. Institutions in SEMINAL—Student Engagement in Mathematics through an Institutional Network for Active Learning—shifted to adapting what we have learned about institutionalizing active learning and inclusive practices to this new virtual education space. Although students and faculty will not return to the same classrooms they left, these lessons from SEMINAL will enhance engagement of all students in their own learning to heighten their success.

SEMINAL addresses a critical challenge facing STEM education. Far too many students, 25-30%, receive grades of D, F, or Withdraw (DFW) from Precalculus and Calculus courses. These are the lowest rates of any college entry-level classes; when combined, Precalculus and Calculus courses are among the three top-attended entry-level courses at universities. The good news is that more students succeed at a few institutions than most others. SEMINAL seeks to create a system in which large numbers of faculty and institutional leaders learn and adapt—as their own—what is known by *some faculty*, in *some classrooms*, at *some institutions*.

It is a national problem that almost a million students annually do not pass Precalculus or Calculus. Of particular concern, students from underrepresented groups, as a whole, have lower success than their majority peers. If they cannot succeed in these entry courses, they lose the opportunity to pursue a major in STEM fields. Not only does this deny these students the personal opportunities for exciting and well-paying careers, it also robs the nation of a more diverse STEM workforce. Left untended, the personal and national toll will only increase—as in the aggregate, present underrepresented groups will become the majority of the U.S. population in less than two decades.

Transforming STEM education to help all students achieve their potential is often simplified as “how to scale” promising practices. But it’s more than simple replication of a practice that worked elsewhere. How do we create a resilient education system of reliable, consistent adaption of proven practices for sustained student success across different classrooms in a variety of institutional contexts?

In *Calculus Reform: What Is Different This Time?* David Bressoud describes how the calculus reform movement of some 35 years ago was all about reforming course content. He notes a certain naiveté about that effort, with its assumption that simply rewriting the texts would automatically lead to widespread institutional adoption of more effective teaching. Today we realize that to convey that content, we need to both engage students in active learning and their institutions in adapting effective practices.

These are the lessons in this foundational volume. Faculty and institutional leaders in diverse institutions have learned how to enhance student success in mainstream Precalculus through Calculus 2 courses for their circumstances and context. This book tells the stories and analyzes the development and implementation of practices that worked and how they were adapted by a purposeful variety of six institutions. The study includes not only how faculty practice active learning, but also how departments enact programs and structure to use active learning precepts to enhance student success and, overall, how institutions provide the context for these efforts.

This volume is the first phase. SEMINAL's second phase brings another nine institutions into a network to study how faculty from varied institutions adopt these changes for their classes, sharing their progress and experiences. In a third phase, SEMINAL has invited about an additional 12 non-networked institutions to compare progress with the existing SEMINAL community. The broader intention will be to build a larger movement from these two dozen institutions to promote national systemic change.

Returning to Bressoud's question: *What is different this time?* SEMINAL is not simply a research project attempting to understand local change. The project makes explicit diversity, equity, and inclusive practices to meet the needs of all students. It strives to understand and enact change **across all key stakeholders across an entire system**. SEMINAL is: energized by creative and smart young faculty, instructors, and graduate students; guided by the wisdom of senior faculty and departmental leaders; learning from peers undertaking parallel work in other institutions; supported by departmental and college administrators; proving what is possible to institutional leaders while challenging them to provide appropriate resources; aligning with efforts of national disciplinary societies—MAA and AMS; and communicating the promise and needs to institutional leaders through a national university association—the Association of Public and Land-grant Universities.

Mathematics faculty, instructors, departmental and institutional leaders: SEMINAL invites you to glean the lessons of this first volume, compare with your own successes and integrate them into contemporary and post-COVID instruction to transform entry-level calculus. We hope you will connect with SEMINAL partners to build a system in which all STEM courses, and all university instruction, further student success, to help students achieve their potential and help them begin on the path to a rewarding and satisfying career.

Howard Gobstein
Executive Vice President
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How to Use This Book

This book is divided into four main parts. Part I provides an overview of SEMINAL. This includes a chapter giving an overarching view of the SEMINAL project and is meant to provide readers with an understanding of the motivations and theory that drive this work, followed by a chapter on the research design of SEMINAL. Part II contains case studies of the six institutions we selected for the first phase of SEMINAL. In Part III we present cross-case analyses of these institutions, focusing on change levers we identified as critical in their efforts to successfully establish active learning as the norm for instruction in the Precalculus through Calculus sequence. Part IV synthesizes what we have learned about change, providing a list of recommendations for change agents operating at various levels of the system. What follows is a recommendation for how to use each section of this book, as well as a more thorough description of what each chapter entails.

Part I: Overview of SEMINAL

In Chapter 1 we describe our motivation for the SEMINAL project, as well as the recent research and calls for educational innovation that have informed this work, before providing summaries of the six selected sites and an introduction to six factors we found to be potentially relevant in affecting change at the departmental level. Chapter 1 provides a bird's-eye view of the project, and as such we recommend that all readers begin here. In Chapter 2 we detail our research methods, including our site selection, data collection, and data analysis procedures. Readers who are primarily interested in the results and recommendations from this book may skip Chapter 2 without disrupting the flow of the book.

Part II: Six Case Studies

Part II contains six chapters, Chapters 3 through 8, each of which presents individual case study reports of one of six sites that have successfully established active learning as the norm for instruction in the Precalculus through Calculus sequence for at least three years. The case study reports provide a narrative of how and why each institution accomplished this transformation. Each of Chapters 3 through 8 are self-contained in that they each present the change story of one institution. Institutional summaries can be found at the end of Chapter 1. Readers may find these summaries useful in prioritizing which chapters to read first. We suggest starting with institutions that are similar to the reader's institutional context.

Part III: Levers for Change

Part III contains Chapters 9 through 16, which present cross-case analyses organized by the following topics: active learning, leadership, coordination, professional

development, student engagement, resources, equity and culture, and sustainability. Chapter 9 focuses on active learning, which is central to the SEMINAL project. All of the institutions involved in SEMINAL are working to support the use of active learning in their Precalculus through Calculus courses. As such, this chapter is critical to this volume. It provides both an overview of SEMINAL's vision for active learning, as well as an analysis of the ways in which active learning strategies are being used at the six Phase 1 SEMINAL sites, and what challenges the sites are facing in their implementation of active learning. The rest of the chapters in this section focus on levers which we identified as influential in supporting the institutionalization of active learning at these six sites. Since change efforts work best when the whole system is considered, we recommend that change agents read each of these chapters in their entirety; however, the reader may want to prioritize certain chapters based on their local priorities and needs.

Part IV: Summarizing What We've Learned

Part IV is Chapter 17, which is a summary of recommendations to readers looking to enact similar reforms, including department chairs, instructors, and campus administrators. In this part of the book we also include a sneak peak into what to expect from future work of the SEMINAL study. We recommend that the reader use this last chapter as a reference guide, as it provides a manageable list of recommendations associated with each one of the critical change levers we identify earlier in the book.

Common Terms, Definitions, and Abbreviations

0.1. List of Abbreviations

- DFW: Drop, Fail, and Withdraw. These represent the rates of students who drop, fail, or withdraw from mathematics courses.
- IBL: Inquiry-Based Learning. Inquiry-based learning is a type of active learning.
- MCOP²: Mathematics Classroom Observation Protocol for Practices. This was the classroom observation instrument used during the project.
- NSF: National Science Foundation.
- SEMINAL: Student Engagement in Mathematics through an Institutional Network for Active Learning.
- STEM: Science, Technology, Engineering, and Mathematics.
- X-PIPS: X-Postsecondary Instructional Practice Survey. This represents the suite of surveys (instructors, students, teaching assistants) that were administered in this project.

0.2. SEMINAL Terminology

- Academic advisor: Non-academic administrator, which includes student support services and other academic advisors.
- Academic dean: Includes deans of colleges and associate/assistant deans.
- Active learning classroom: Classroom spaces designed to support student collaboration, usually featuring movable tables and chairs and extensive board space.
- Adjunct: Includes people hired to teach mathematics courses, not on a tenure-track line; can be full or part time. Includes lecturers, instructors, adjuncts, etc.
- Assistant chair: Vice chair, associate chair, etc.; a person who is not the department chair or head but assists in department administration in an official capacity.
- Campus administrator: Refers to university administrator at a high level, such as provost, assistant provost, chancellor, vice chancellor, etc.; does not include deans or department chairs/heads.
- Client discipline: Physical science and engineering departments whose students are required to take at least Calculus 1 and often Calculus 2; does not include business or biology majors when there are special sections of Calculus for them (e.g., Calculus for Life Sciences).
- Coordinator: Faculty member or other staff who has responsibility for coordinating one or more Precalculus through Calculus courses, such as setting the syllabus, selecting the text, setting the homework, and writing

the assessments. Coordinators may observe and monitor what is being taught and usually lead regular course meetings of instructors. Sometimes called conveners.

- Department administrator: Can refer to anyone in the department with a formal leadership role, such as chair/head or assistant chair.
- Department chair: The chair, head, or director of the math department.
- Faculty: Tenured or tenure-track faculty, as well as others with “permanent” status such as professors of practice.
- Graduate student instructor: Graduate student with teaching responsibilities, also called graduate teaching assistant.
- Instructors: Anyone who is teaching Precalculus through Calculus courses as an instructor of record, regardless of role (e.g., faculty, postdoc, adjunct, graduate student instructor).
- Lead Coordinator: Faculty member or other staff who oversees the Precalculus through Calculus 2 coordination (multiple courses). May also have responsibilities of coordinators.
- Lead graduate student instructor: A graduate student instructor who assists the course coordinator.
- Mainstream Precalculus through Calculus: The calculus sequence for physical science and engineering students; does not include courses that are only for specific subsets of students such as Calculus for Biology or Business Calculus.
- Precalculus through Calculus committee: A faculty committee that oversees one or more Precalculus through Calculus courses, focused on the reforms. They may review local data, oversee coordinators, determine curricular changes, review assessments, etc.
- Postdocs: Postdoctoral position with teaching responsibilities; not in a tenure-track.
- Professors of Practice: Includes teaching professors and clinical professors; these are faculty members (not tenure-track), for whom most of their appointment is devoted to the teaching/instructional mission of the department. Contracts tend to be multi-year.
- Professional development: Includes trainings, workshops, and other activities designed to help instructors improve their instructional practices. Can include one-on-one mentoring, weekly meetings, etc.
- Recitation: Also called labs, discussion sections, breakouts. These are small (around 15-30 students) sections associated with large lecture classes, often led by a graduate student instructor or undergraduate learning assistant, that meet 1-3 times per week, separate from the large lectures. These are regular sessions that all students in the large lecture are expected to attend.
- Supplemental instruction: Small sections associated with a Precalculus through Calculus course (can be large or small lecture), designed for “at-risk” students (often through placement test identification or other student characteristic such as a first-generation college student). These sessions are designed to address gaps in student knowledge, and otherwise help support students in being successful in the primary Precalculus

through Calculus course with which the supplemental instruction is associated. Supplemental instruction is often optional (or, once students opt in, all sessions are required).

- Teaching and learning center: A center where faculty go as a resource; such centers may provide professional development for faculty and other instructors.
- Tutoring center: Where students go to get help with mathematics; the Director of the Tutoring Center is in charge of this place.
- Undergraduate learning assistant: An undergraduate who assists with Precalculus through Calculus instruction (not as an instructor of record). May also be called learning assistant, instructional learning assistant, instructional student assistant, undergraduate student assistant, or supplemental instructor on particular campuses. Undergraduate learning assistants may be alone in a classroom with students (e.g., running a lab or breakout section) or may be in a classroom with a lead instructor. Does not include undergrad whose only role is in a tutoring capacity. Undergraduate learning assistants are paid, have regular hours, and have responsibilities within classroom instruction environments.

Executive Summary of Transformational Change Efforts: Student Engagement in Mathematics through an Institutional Network for Active Learning

The purpose of this handbook is to help launch institutional transformations in mathematics departments to improve student success; the intended audience is faculty and department chairs in collegiate mathematics departments. To achieve this goal, we report findings from the **Student Engagement in Mathematics through an Institutional Network for Active Learning** (SEMINAL) study. SEMINAL's overarching purpose is to help *change agents*, those looking to (or currently attempting to) enact change within mathematics departments and beyond, who are trying to reform the instruction of their lower-division mathematics courses in order to promote high achievement for all students.

Why This Handbook?

- SEMINAL specifically studies the change mechanisms that allow postsecondary institutions to incorporate and sustain *active learning* in Precalculus through Calculus 2 learning environments.
- Out of the approximately 2.5 million students enrolled in collegiate mathematics courses each year, over 90% are enrolled in Precalculus through Calculus 2 courses [3].
- 44% of mathematics departments think active learning mathematics strategies are important for Precalculus to Calculus 2 courses, but only 15% state that they are very successful at implementing such strategies [4].
- Therefore, insights into the following research question will help with institutional transformations: What conditions, strategies, interventions, and actions at the departmental and classroom levels contribute to the initiation, implementation, and institutional sustainability of active learning in the Precalculus through Calculus 2 courses across varied institutions?

What is Active Learning? Laursen and Rasmussen [3] reviewed different types of inquiry-oriented and inquiry-based mathematics instruction, and synthesize multiple traditions to identify four pillars for inquiry-based mathematics education:

- Students' deep engagement in mathematical thinking;
- Peer-to-peer interaction;
- Instructors' interest in and use of student thinking;
- Instructors' attention to equitable and inclusive practices.

This definition includes behaviors for both instructors and students, and includes an explicit focus on equity. A key goal in utilizing active learning strategies is to improve student outcomes; without an explicit attention to issues of equity and inclusion, inquiry-based mathematics education strategies may perpetuate current inequities in mathematics outcomes.

What is Necessary to Enact and Sustain Institutional Change? Undergraduate institutions are, by design, resistant to change. Change is hard to implement, and sustain, from the organization of majors, to course syllabi, to expected classroom practices. Keys to initiate, implement and sustain change include:

- Systemic approaches;
- Understanding institutional change;
- A focus on improved student engagement and equitable student outcomes;
- Active learning;
- Effective leadership
- Departmental and institutional cultures that encourage educational improvements;
- Course coordination;
- Professional development;
- Instructor communities of practice;
- Resources to improve teaching and learning;
- Use of local data.

SEMINAL builds on the *Characteristics of Successful Programs in College Calculus* project [1, 2, 4, 5] that identified eight key features of successful Calculus 1 programs in the United States. SEMINAL's retrospective study (Chapters 1-2) of six mathematics departments (Chapters 3-8) that were able to successfully sustain improvements to their Precalculus through Calculus 2 courses affirmed the eight characteristics of successful calculus programs [1, 2, 4, 5]. Each institution took a somewhat different route in achieving this goal, providing a range of examples for those seeking to make similar changes. Despite the different routes, common themes emerged across the six cases, suggesting key levers in promoting those changes. The SEMINAL team undertook an analysis cutting across the institutions, focusing on common aspects of the change experience (Chapters 9-16), which led to the identification of the following key change levers (Chapter 17). Most of these levers are mentioned throughout the chapters; the chapters highlighted in the table indicate where the lever is discussed in depth.

Change Levers and Key Considerations	Chapters
Systemic approach	
<p>The current situation was not caused by a single event or person. Effective changes look broadly to “see the system” and address root causes, not just symptoms.</p> <p><u>Corollary:</u> You need a big enough team to represent different system components (student recruitment, placement, advising, teaching & learning center, campus data, facilities, scheduling, finance, academic affairs, deans, department chairs, instructors, tutoring centers, etc.).</p>	1, 3-8
Understanding institutional change	
<p>Institutional change as a topic has research indicating best practices: Moving from initiating change on a small scale, scaling it up to additional courses, and working to institutionalize the changes so that they are sustained. However, there is not a singular “correct” path to effective transformation, nor is there a singular “best” team of people to work collaboratively on change efforts.</p> <p><u>Corollary:</u> Successful transformation efforts involve multiple stakeholders working through the change process toward a common vision of improved student outcomes in mathematics.</p>	1, 3-8, 16
A focus on improved student engagement and equitable student outcomes	
<p>The national status quo leads to inequitable student outcomes by most subgroups (gender, ethnicity, socioeconomic status, first generation). Keeping a focus on improving equitable student outcomes, and making sure decisions are made that prioritize the needs of students are crucial.</p> <p><u>Corollary:</u> Putting students into groups and using active learning strategies does not automatically increase equity; instructors need to explicitly address developing norms for interaction that encourage mathematical reasoning and communication for all students.</p>	12, 15
Active learning	
<p>Following the active learning definition above, students need to be actively engaged in making sense of mathematics and communicating mathematical thinking and reasoning.</p> <p><u>Corollary:</u> Active learning takes more time than simply telling students information via lectures. Departments may address this through a combination of adding more minutes to courses using active learning, and trimming the learning objectives for the targeted courses.</p>	1, 9
Effective leadership	
<p>Leaders who are willing to push for changes that will improve student success are needed at all levels, from campus administrators to department chairs and faculty committees. Motivated change agents are needed to keep the change efforts as a long-term priority.</p> <p><u>Corollary:</u> Effective teams have a transition plan to bring new leaders on board both within and without the department.</p>	3-8, 10, 16
Departmental and institutional cultures that encourage educational improvements	
<p>Change occurs more quickly when individuals who need to make changes have sufficient incentive. Annual evaluations (and merit raises) that reward attempts to improve instruction are important.</p> <p><u>Corollary:</u> It is not enough that effective teaching is, valued on paper; actions, resources and policies of administrators need to align with the importance of instructional innovations.</p>	3-8, 15

Course coordination	
More consistent courses across sections and semesters can help reduce inequitable outcomes and improve in-house professional development opportunities. Coordination also provides institutional memory through changes in instructors assigned to teach specific courses. <u>Corollary:</u> Coordination of learning objectives across courses can help reduce redundancy, leaving more time to focus on key learning objectives within individual courses.	3-7, 11
Professional development	
Instructors cannot just stop lecturing and inherently know how to actively engage students while maintaining rigorous mathematical expectations. The entire instructional workforce (from tenured/tenure-track faculty to adjuncts, graduate student instructors, and undergraduate student assistants) needs to learn how to engage students actively. <u>Corollary:</u> Effective professional development includes both initial workshops and sustained semester-long support.	13
Instructor communities of practice	
When the norm is for instructors to discuss teaching and learning with each other (akin to research groups), then instructors can learn from each other and better implement and sustain improved educational practices. <u>Corollary:</u> Departments need explicit plans for integrating new instructors into an existing community of practice.	3-8, 13, 15
Resources to improve teaching and learning	
Improved student outcomes are not free. Although it takes time and money to effectively improve student outcomes, effective transformation does not necessarily need a huge amount of monetary resources. <u>Corollary:</u> Instructional innovation is a personnel-intensive activity; undergraduate learning assistants can be a low-cost resource to support active learning.	3-8, 14
Use of local data	
Departments need access to relevant local data (and often to collect their own data) in order to make informed decisions, and to measure the impact of change efforts. Local data include far more than final grades in mathematics courses, potentially including: Course-taking trajectories, majors, enrollment numbers, grades in subsequent mathematics courses, item-level homework and test performance, attendance, use of student supports (tutoring centers, office hours), attitudes toward mathematics. These data should be disaggregated by targeted subgroups (e.g., by gender, first-generation, Pell-eligible). <u>Corollary:</u> Changes take time to show up in data, particularly longitudinal data like course-taking trajectories, STEM majors, and graduation rates. It is common to see an “implementation dip” the first time instructors attempt new teaching strategies.	2-8, 16

References

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Chapter 1

The Student Engagement in Mathematics through an Institutional Network for Active Learning (SEMINAL) Project: An Overview

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1.1. Introduction and Motivation

The intent of this volume is to help launch institutional transformations in mathematics departments to improve student success; the intended audience is faculty members and department chairs in collegiate mathematics departments. To achieve this goal, we report findings from the beginning phase of the Student Engagement in Mathematics through an Institutional Network for Active Learning (SEMINAL) study. SEMINAL's overarching purpose is to help change agents, those looking to or currently attempting to enact change, within mathematics departments and beyond who are trying to reform the instruction of their lower-division mathematics courses to promote high achievement for all students.

SEMINAL specifically studies the change mechanisms that allow postsecondary institutions to incorporate and sustain *active learning* (defined below in Section 1.1.1.1) in Precalculus through Calculus learning environments. Whereas several studies have illustrated the potential benefits of active learning use in collegiate environments, lecture-based instruction remains largely entrenched within universities across the nation [5, 37]. Benefits to actively engaging students include increased student learning (grades in courses, subsequent courses, retention in STEM majors), improved graduation rates, and more equitable outcomes (smaller gaps between different subgroups of students). Research provides limited direction to those individuals looking to engender lasting change and establish new evidence-based instructional practices as the departmental norm for teaching Precalculus through Calculus courses.

SEMINAL addresses this by studying institutions that have successfully enacted such desired changes, in addition to studying change processes as they occur

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at a variety of institutional contexts looking to reform their Precalculus through Calculus courses. As a five-year collaborative research grant from the National Science Foundation (DUE-1624643, 1624610, 1624628, 1624639), SEMINAL has two major phases. Phase 1 consists of case studies at six institutions that have a record of successfully implementing *active learning mathematics* strategies in Precalculus through Calculus and that represent both diverse institutional settings and student demographics. Phase 2 consists of longitudinal, incentivized case studies of nine diverse institutions that are infusing active learning into the Precalculus through Calculus sequence as they participate in a *networked improvement community*. Here the phrase “Precalculus through Calculus” includes Calculus 2. The current volume focuses on results from the first phase of the project, in which we built retrospective accounts of active learning mathematics models of change that worked, and present change levers utilized by each of the Phase 1 institutions to institutionalize active learning and sustain improved student outcomes within their departments.

1.1.1. Rationale. Out of the approximately 2.5 million students enrolled in collegiate mathematics courses each year, more than 90% are enrolled in Precalculus through Calculus courses [21]. Thus, a concern for Precalculus through Calculus courses is a concern for the vast majority of college mathematics students. Hundreds of thousands of students fail Precalculus through Calculus courses each year; such failures can derail their planned degrees and majors, particularly STEM majors. The status quo is not working for a large number of students; historically under-represented students are disproportionately those for whom the current system is not working.

Over the past three decades, numerous entities have called for a transformation of lower-level undergraduate mathematics programs to improve student success. Despite several attempts to improve these courses, undergraduate students are often dissuaded from persisting in STEM, and some students discontinue their postsecondary education altogether [10, 12, 27, 28, 30, 38]. The Mathematical Association of America’s *Common Vision from Math Programs in 2025* [36] analyzed seven curricular guides developed by the American Mathematical Association of Two-Year Colleges, American Mathematical Society, American Statistical Association, Mathematical Association of America, and Society for Industrial and Applied Mathematics and came to the conclusion that, in reference to the instruction of undergraduate mathematics, the status quo is unacceptable.

These organizations call upon the mathematics community to work toward improving undergraduate mathematics instruction, particularly in lower-division mathematics courses. Part of their recommendations center on the need to scale up the use of evidence-based instruction. They contend that active learning models, which engage students in activities that promote analysis, synthesis, and evaluation, are more effective than traditional lecture-based classrooms.

1.1.1.1. *Defining active learning.* Active learning does not have a single definition in the literature, although the phrase is commonly used to describe teaching methods that acknowledge students should do more than act as “receptacles of knowledge” [35, p. 20], that they should be developing skills by working on tasks that promote higher-order thinking (including analysis, synthesis, and evaluation of content), and exploration of content [2].

Often, definitions of active learning focus on students, such as Freeman et al.'s [13] consensus definition in their report on the efficacy of active learning: “Active learning engages students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert. It emphasizes higher-order thinking and often involves group work” (pp. 8413-8414). Many active learning strategies encourage peer interaction, implicitly acknowledging that student learning is facilitated by discussion of the content with others [20].

Laursen and Rasmussen [24] reviewed different types of inquiry-oriented and inquiry-based mathematics instruction, and synthesize multiple traditions to identify four pillars for inquiry-based mathematics education:

- Students engage deeply with coherent and meaningful mathematical tasks.
- Students collaboratively process mathematical ideas.
- Instructors inquire into student thinking.
- Instructors foster equity in their design and facilitation choices. (p. 20)

This definition includes behaviors for both instructors and students, and includes an explicit focus on equity. A key goal in utilizing active learning strategies is to improve student outcomes; without an explicit attention to issues of equity and inclusion, inquiry-based mathematics education strategies may perpetuate current inequities in mathematics outcomes [17]. We take the stance that efforts to improve Precalculus through Calculus courses and student outcomes must include a focus on achieving more equitable student outcomes.

Research shows that the use of active learning strategies, with supporting campus structures (e.g., a robust placement policy, course coordination), has the potential to improve student learning, achievement, and persistence in STEM-related fields [5, 13, 23, 31]. For instance, active learning was found to be one of the seven key characteristics of successful calculus programs in a national survey [5] and Freeman et al.'s meta-analysis of studies involving active learning across STEM disciplines showed overwhelmingly positive evidence of improved student success compared to more traditional lecture classes [13]. Some researchers have looked at mathematics success by gender, and found positive impacts of active learning for all students, but especially for women [23]. Active learning strategies also have the potential to elicit high levels of academic achievement for underrepresented groups [22], which is particularly important in light of research that suggests that women and underrepresented minority students struggle with persistence in STEM at a greater rate than others [22, 36].

1.1.1.2. *The purpose of SEMINAL.* In response to research on the effectiveness of active learning environments, numerous postsecondary U.S. institutions are attempting to integrate such strategies into their lower-division courses. Although this change is encouraging, wholesale change efforts in higher education are demonstrably slow [18] and the uses of such research-based practices are not yet mainstream [5, 14, 21, 37]. Rasmussen et al. [29] report on a survey of all United States mathematics departments that grant graduate degrees and found that 44% of such mathematics departments think active learning mathematics strategies are very important for Precalculus through Calculus courses, but only 15% state that they are very successful at implementing them. Thus, there is a significant need to help departments implement active learning mathematics strategies.

Compelling arguments for the adoption of active learning strategies exist, but the change process and contextual factors that allowed for such success need further articulation to be useful to the broader educational community, as prior research in first-year undergraduate mathematics courses has not moved the field in a significant way [32]. The SEMINAL study hopes to catalyze a shift in what is considered normative instruction in first-year undergraduate mathematics courses to accommodate active learning by illuminating potential pathways for initiating, implementing, and sustaining changes to these departmental norms. The project focuses on large-enrollment entry-level courses—Precalculus to Calculus 2—due to the pivotal role these courses play in retaining and recruiting STEM majors. The main objectives of the project are to:

- Understand what strategies mathematics departments have employed to set up and sustain active learning environments in their Precalculus through Calculus sequence, with a focus on understanding how those strategies were informed by contextual factors (i.e., institutional factors);
- Identify potential pathways for change and related strategies to improve undergraduate success in high-enrollment mathematics courses using active learning mathematics principles that mathematics departments can adapt to meet their particular circumstances;
- Use the Association of Public and Land-grant Universities’ engagement with university leaders and leveraged incentives to catalyze change in universities that participate in SEMINAL’s networked improvement community (key faculty at selected Phase 2 institutions will implement active learning mathematics locally in Precalculus through Calculus courses, engage in data collection and analysis, and communicate ongoing findings and share resources in order to improve implementation of active learning mathematics in the Precalculus through Calculus sequence); and
- Generate models of cultural change that support active learning in lower-division undergraduate math courses.

The purpose of this volume is to relay our findings toward the first objective. The remaining objectives will be addressed in other locations at the completion of the second phase of SEMINAL. The first phase consists of retrospective case studies at six institutions that have a record of successfully implementing active learning mathematics in their Precalculus through Calculus sequence for at least three years and that represent both diverse institutional settings and student demographics.

Key Takeaway:

44% of mathematics departments think active learning mathematics strategies are important for Precalculus through Calculus courses, but only 15% state that they are very successful at implementing them.

1.1.2. Origins of SEMINAL. The SEMINAL project grew from efforts by the *Active Learning Mathematics Research Action Cluster* to understand how infusing active learning strategies in the Precalculus through Calculus sequence ultimately improves student achievement. The Active Learning Mathematics Research Action Cluster focused on how a handful of faculty members in a department could initiate the implementation of active learning strategies. The Active

Learning Mathematics Research Action Cluster received a small grant from the Helmsley Charitable Trust (2013-2015) to study how effectively five departments were able to scale up efforts to implement active learning strategies. One of the critical findings of this project was that it is not enough to know that active learning can positively affect student achievement; departments need direction in how to initiate, effect, and sustain institutional change. Further, the department chair played a key role: when the chair was not an active proponent of scaling up the effective implementation of active learning, efforts by faculty did not extend much beyond the faculty who were already interested in doing so. This finding about the importance of the chair was unexpected, since the premise of the group was that a collection of passionate faculty could successfully initiate changes to adopt active learning that would be taken up by others in the department. Further, the Active Learning Mathematics Research Action Cluster research underscored that when changes were centered on individual faculty, such changes were ephemeral, and likely to disappear if those faculty were no longer teaching Precalculus through Calculus courses, much less if those faculty moved to a different institution.

The key to sustainable course reforms seems to depend much more on departmental and institutional cultures than on a few passionate individuals. Members of the Active Learning Mathematics Research Action Cluster proposed SEMINAL to the National Science Foundation in order to better understand the change stories of several institutions that had successfully institutionalized the implementation of active learning strategies, and to attempt to induce similar cultural shifts in a number of institutions wanting to implement active learning strategies. SEMINAL was designed to address a gap in understanding what systemic institutional changes are needed to support active learning environments, attempting to answer the overarching research question:

What conditions, strategies, interventions, and actions at the departmental and classroom levels contribute to the initiation, implementation, and institutional sustainability of active learning in the undergraduate calculus sequence (Precalculus through Calculus) across varied institutions?

The Active Learning Mathematics Research Action Cluster is part of the larger Mathematics Teacher Education Partnership, formed to address the United States' shortage of well-qualified secondary mathematics teachers [25, 26]. The overarching goal of the Mathematics Teacher Education Partnership is to address this problem by improving secondary mathematics teacher preparation programs. The Partnership includes approximately 40 teams across 31 states, with members from various components of the education system: from universities to K-12 districts to state departments of education. Members of the Mathematics Teacher Education Partnership are organized into *research action clusters*, which each address a specific problem in secondary mathematics preparation and are working to develop potential solutions that other teams in the Mathematics Teacher Education Partnership can test. Their work is based on a *networked improvement community* model for achieving transformational change [6, 7, 25, 26].

In a networked improvement community [6, 7, 25, 26], a group of stakeholders come together and agree on a common vision for positive changes. The group seeks to understand the current system that supports and perpetuates the status quo, particularly to identify root causes of the identified problem. The group then

hypothesizes primary drivers for change: what are the levers by which change might be achieved? The group then often splits into subgroups, each focused on one of the primary drivers. Each subgroup engages in short-term (usually less than a semester) inquiry cycles of plan-do-study-act, in which they seek to quickly test out various change ideas. The subgroups and the whole group regularly reflect on progress. Key to an improvement community being “networked” is the regular communication across subgroups, so that everyone can benefit from the entirety of the project. Networked improvement communities are a promising approach to not only affecting change but also accelerating the change process beyond what an individual can accomplish alone.

Each of the research action clusters can be considered a networked improvement community in and of themselves [26]. The Active Learning Mathematics Research Action Cluster contributes to the objectives of the Mathematics Teacher Education Partnership by addressing lower-division mathematics courses, which can serve as a barrier to prospective secondary mathematics teachers. Improving introductory mathematics courses has the potential to both retain those interested in pursuing a degree as a secondary mathematics teacher as well as encourage new recruits. The Active Learning Mathematics Research Action Cluster was created based on the desire for improved learning outcomes for prospective teachers, which research shows is more likely in an active learning environment as opposed to a traditional lecture-based one. Founders of the Active Learning Mathematics Research Action Cluster also wanted prospective teachers to experience active learning environments as students, so that they could witness firsthand the potential advantages such a classroom holds for teaching mathematics. The findings from SEMINAL feed directly back into the Active Learning Mathematics Research Action Cluster, so that the research results can inform current change efforts by Active Learning Mathematics Research Action Cluster members.

1.1.3. Theory of Institutional Change. Undergraduate institutions are, by design, resistant to change [1]. From the organization of majors, to course syllabi, to expected classroom practices, change is challenging to implement and sustain. However, research on instructional change [15, 18, 21, 34] has shown that with well-articulated goals, leadership, and proper incentives, these traditions can be disrupted so that changes to the status quo can be enacted and sustained through key institutional supports that retain innovations as the new normal. Further, effective institutional changes are systemic; the current situation has a long history and is deeply embedded in institutional cultural traditions and norms. As Corbo et al. [8] suggest, systems-level thinking is necessary to ensure the success of change initiatives. Systems-thinking refers to the notion that connections between variables tend to be complex, and focusing on one individual’s change efforts does not lead to systemic reform of a department, rather “successful change agents use multiple approaches to create change that are matched to the type of change desired and the context within which they are pursuing it” [18, p. 52]. Effective change strategies need to be multidimensional to address multiple causes of the current situation.

Calls for improvements to introductory undergraduate STEM courses have coincided with insights and research on departmental and institutional change. Kezar [18] synthesized research on institutional change efforts, and, in particular, documented common reasons change efforts fail; she cites the rate of failure of attempted institutional changes as 70%. Kezar starts by noting, “Most change agents believe

that once they have a vision or idea for change the major work is done, that implementation is nothing but an afterthought” (p. x). Key mistakes change agents make include ignoring the process of change, ignoring context, creating overly simplistic change models, and not grounding change in research. Borrego and Henderson [3] point out that most change agents focus on a single change strategy, which then proves ineffective because a single strategy rarely works with all stakeholders and is insufficient to address complex educational systems.

Elrod and Kezar [11] further caution that effective change strategies start with a common vision, involve key stakeholders, and align efforts to campus strategic plans and priorities. Failed change efforts share common features: assuming change implements itself once a vision is articulated, ignoring contextual factors, creating overly simplistic change models, and ignoring relevant research [3, 11, 18]. SEMINAL addresses all of these commonalities by understanding that changes need intentional and complex implementation plans, focusing on how contextual features will be incorporated or altered and building from known institutional change research.

Research around institutional change is a fairly recent phenomenon in higher education [21]. Some researchers have borrowed from institutional change literature in the business world, which has a much longer history. Reinholz and Apkarian [33] drew on business literature to adapt four frames for effective change to higher education: people, power, symbols, and structures. Effective institutional change needs to consider these four frames and their interactions. The people involved include department and institutional leaders as well as Precalculus through Calculus instructors and students. People and groups have varying levels of power, including the authority to make intended changes. Symbols refer to the beliefs and attitudes of the people involved, including beliefs about teaching and learning, mathematics, student capabilities, and uses of technology. Structures can be physical, such as classrooms, or organizational, such as a faculty task force to oversee Precalculus through Calculus courses, or training for graduate student instructors.

Consistent with a systems perspective is taking a holistic view of what needs to be attended to when planning for, initiating, and sustaining departmental change. The *Characteristics of Successful College Calculus* program [5, 29] identified seven key features of successful Calculus 1 programs in the United States:

- (1) Attention to the effectiveness of placement procedures.
- (2) Proactive student support services, including the fostering of student academic and social integration.
- (3) Construction of challenging and engaging courses.
- (4) Use of student-centered pedagogies and active learning strategies.
- (5) Coordination of instruction, including the building of communities of practice.
- (6) Effective training of graduate teaching assistants.
- (7) Regular use of local data to guide curricular and structural modifications.
(p. viii)

The *Progress Through Calculus* program has expanded these dimensions, including a focus on continuous improvement processes, leadership, and issues of diversity, equity, and inclusion. Mathematically coherent curriculum and the related activities and tasks are a necessary but insufficient condition for a classroom to be categorized as active learning mathematics. Also critical are norms for discourse

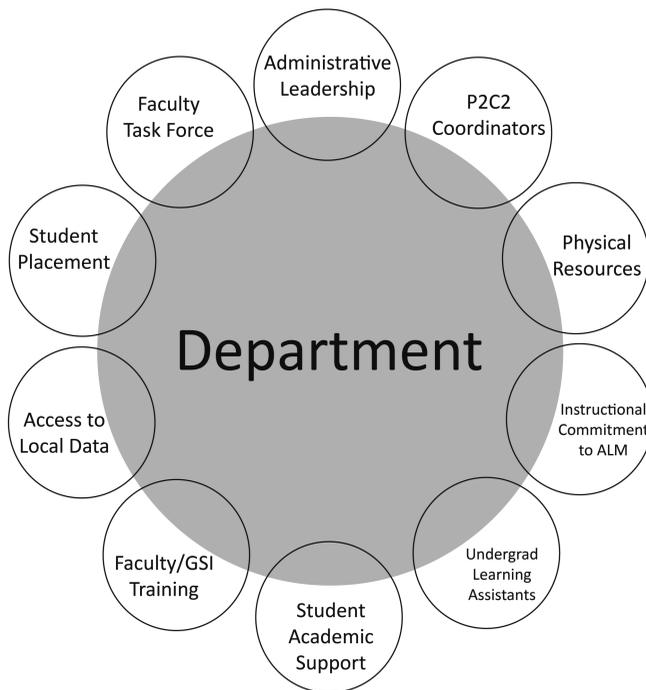


FIGURE 1.1. SEMINAL departmental-level hypothesized change levers for initiating, implementing and sustaining institutional change to improve student outcomes in Precalculus through Calculus (labeled “P2C2”) courses. Here “ALM” refers to active learning in mathematics; “GSI” refers to graduate student instructors, often called graduate teaching assistants.

and peer-to-peer interaction, as well as instructor decisions, uses of assessments, and instructor inquiry into student thinking. Such inquiry provides opportunities for the instructor to connect and relate student ideas to conventional and formal mathematics and to pose appropriate follow-up tasks and assignments that build on student thinking to advance the mathematical agenda.

The key active learning mathematics features at the department level (see Figure 1.1) align both with the *Characteristics of Successful College Calculus* findings for effective calculus programs, the active learning findings in various science disciplines [13, 21], and the features of effective institutional change [18]. Specifically, campus and department leadership are crucial to successful institutionalization of active learning mathematics. However, faculty leadership is also critical through some type of faculty task force focused on introductory mathematics and/or through a precalculus/calculus coordinator. Effective departments attend to student data, particularly placement data, student trajectories through courses, and student success. The networked improvement community functions as the background to support these local features, along with the institutional culture related to educational innovation and community culture.

Physical resources can accelerate or hinder the institutionalization of active learning mathematics models in departments (i.e., active learning mathematics can

be greatly facilitated when classrooms have movable tables/chairs and access to technology for sharing student work). Asking instructors to teach differently requires support in the form of training or professional development for instructors and graduate student instructors, such as a seminar focusing on effective instruction. Utilizing learning assistants can greatly enhance students' engagement with active learning mathematics models, by providing additional instructors to support student group work and discourse. Finally, student support in the form of advising, tutoring centers, and other structures can help increase student success.

Systemic institutional change efforts are not one-size-fits all, and need to adapt to local contexts. Dancy, Henderson, and Turpen [9] emphasize that knowledge of effective pedagogical practices and access to appropriate curriculum materials are insufficient for instructional adoption. Instructors need to buy in to improving their instructional practices and need training in how to improve their instruction. It is not enough to simply tell people to stop lecturing. Stains et al. [37] showed more recently that, across STEM disciplines, the enactment of evidence-based instructional practices lags awareness of such strategies. Thus, explicit, systemic, research-based strategies for institutional transformation are needed to undertake change efforts.

1.2. The Phase 1 Institutions

In this section we briefly describe contextual features of each of the institutions studied in Phase 1 of SEMINAL, as well as short summaries of their change stories. Throughout this book we have chosen to de-identify these institutions as much as possible, while still reporting enough information to capture those salient program and cultural features that have allowed for sustained change (over a period of three years or more) in Precalculus through Calculus courses. Full chapters about each site's history and contexts are in Chapters 3-8. The pseudonyms we have chosen for each site are:

- Phased Change University
- All-In University
- Crossroads University
- Long-Term University
- Critical Response University
- Grassroots University

Chapter 3: Phased Change University. Phased Change University is an R1 institution whose Precalculus through Calculus sequence has evolved in several phases, the first beginning in the early 1990s with a move from large to small sections. While the bulk of its reforms involving active learning occurred in 2008, the shift to smaller class sizes was seen as critical to the success of later reform efforts. These more recent efforts initially focused on making calculus recitations more beneficial for students. As such, the department has devoted much of its time and resources to change levers that help sustain active learning in recitations for Calculus 1 and 2. This includes acquiring and using external funds to create an extensive repository of active learning projects for these recitations, developing graduate students' pedagogical knowledge, and taking advantage of a well-established undergraduate learning assistant program on campus to hire and train undergraduate learning assistants to help run recitations. Like Crossroads University, the

mathematics department is particularly invested in graduate student development, offering multiple forms of professional development including two semesters (first and fourth semester) of a pedagogy course. Further, the department has maintained and expanded a coordination system that supports active learning both in recitations and main class sessions. The sustainability of these efforts is evident by the expansion of this model into Calculus 3.

Chapter 4: All-In University. All-In University is a Hispanic-serving R2 institution with a large commuter population. Its reform story is distinguished by the holistic, evidence-based strategy the mathematics department employed for change, its utilization of synergistic campus initiatives for student success, and the strong involvement of the department chair. Early reform efforts were heavily informed by the features of successful Calculus 1 programs reported in the *Characteristics of Successful Programs in College Calculus* study, and coincided with and capitalized upon a new campus-wide student success initiative launched by the university in 2013 to create new student supports both in and outside the classroom. Efforts by the mathematics department include forming new, small recitation sections with active learning, creating a departmentally controlled mathematics learning center to better support student success outside the classroom, institution of a robust new graduate student training and professional development program, and introducing a comprehensive coordination system.

Much of these efforts were made possible due to the commitment of the department chair and calculus task force, which consisted of mathematics and mathematics education faculty. Sensing the need to change their Precalculus through Calculus program, the department chair directed much of his energy toward improvement efforts and served as a key relationship builder among various stakeholders. In particular, he helped facilitate collaboration between mathematicians and mathematics education researchers to work toward bettering the Precalculus through Calculus program and used his role on a campus task force to procure resources supporting the new recitation sections.

Chapter 5: Crossroads University. Crossroads University's reform efforts were supported by a long-standing departmental history of interest in student success. The mathematics department is particularly distinctive for its commitment to supporting graduate students, strong department leadership, systematic collection and use of data, and innovative strategies for procuring resources. Reform efforts began in 2012 as a result of a newly appointed department chair's decision to abandon the potential adoption of an emporium model in precalculus in favor of a new reform strategy. The mathematics department had piloted an emporium model in precalculus to address low levels of success, but the students enrolled in the pilot fared no better than those enrolled in the traditional course sections. Concerned about the potential ongoing costs of maintaining such a program, losing graduate student lines (graduate students at Crossroads University are largely supported by teacher assistantships), and the dubious impacts of the emporium model on student learning, the department chair tasked a newly minted Precalculus through Calculus committee with reforming and overseeing a new precalculus program. These reform efforts included creating a Precalculus through Calculus committee to plan and oversee changes, implementing active learning into all precalculus sessions,

securing resources to hire new personnel to help develop and run a revamped coordination system, and creating course materials to support instructors in using active learning strategies.

Crossroads University was particularly interested in developing a comprehensive graduate student instructor development program. In particular, a full-time coordinator was hired to help oversee coordination of the Precalculus through Calculus program and run a year-long pedagogy course for graduate students acting as first-time instructors of record. Experienced graduate student instructors gain valuable experience by serving as associate coordinators for individual precalculus courses. Reform efforts have extended to Calculus 1 and 2. The department has been especially creative in finding ways to obtain resources for the sustainment of its program, including leveraging new infrastructure development to design active learning classrooms and hiring undergraduate learning assistants using funds from an in-house-developed course packet.

Chapter 6: Long-Term University. Out of all the Phase 1 institutions, Long-Term University has the longest history of sustaining active learning in its Precalculus through Calculus courses, having sustained active learning in its Precalculus through Calculus courses for over 25 years. As such its change story provides valuable insight into what sustainability looks like over several decades. Long-Term University is an R1 institution with a large number of doctoral graduate students and postdoctoral faculty. It relies on this personnel to teach the majority of its Precalculus through Calculus courses. The mathematics department attributes its success to multiple factors. The department began its reforms by instituting an extensive yet flexible coordination system that has been continually refined and improved over time. To establish active learning as the instructional norm, the mathematics department offers professional development in the form of a pre-semester orientation to all instructors teaching a coordinated course. Currently the mathematics department benefits from being situated in a college that prides itself on its teaching. The college's hiring and promotion practices are designed to attract and retain faculty and lecturers who are committed to teaching. This commitment to education was not always this pervasive, however. Early on in the reform efforts mathematics department chairs played a critical role in supporting and advocating for this coordination system, on occasion having to advocate strongly with upper administrators on its behalf. Contemporary department chairs have extended their support by giving long-term coordinators the power to oversee the system. Besides serving as an example of what long-term sustainment takes, the mathematics department at Long-Term University prides itself on its unique placement system for first-year undergraduate students, considering this to be one of the core components of their program.

Chapter 7: Critical Response University. Critical Response University serves a diverse group of students, holding the designation of being a Minority Serving Institution, an Asian American and Native American Pacific Islander Serving Institution, and a Hispanic Serving Institution. The mathematics department began its change efforts in Summer 2014 after experiencing disastrously low pass rates in Calculus during the prior term. After this crisis, faculty and administrators alike recognized that comprehensive, radical change needed to happen to prevent

such a crisis happening again. The university responded by forming an interdisciplinary task force charged with forming a plan to improve Calculus. Throughout this process the mathematics department took ownership of its role and vision for changes. After extensive review of the literature, the task force chose two broad targets for change efforts: teaching and coordination. Key elements of its reform efforts include hiring coordinators for Precalculus and Calculus, using common exams, implementing instructor meetings, developing materials to support the use of active learning strategies in all components of the course (lecture and recitation), and introducing a strict attendance policy to address low attendance rates, which were deemed as a major hindrance to student success.

Chapter 8: Grassroots University. Grassroots University serves a large minority population. It is an associate member of the Hispanic Association of Colleges and Universities, and is in the top 10 list of U.S. universities for African American graduation rates. Further, about half of its students identify as first-generation college students. Although the mathematics department has a master's program, unlike many other Phase 1 institutions, its Precalculus through Calculus sequence is taught by faculty and adjuncts, a collection of whom have been the heart of the reform efforts. Many of these faculty were hired within the past 15 years and were influenced by their participation in national conferences supporting active learning strategies. Their efforts initially began with their own classes, but by sharing their practice with others, the use of active learning strategies in Precalculus through Calculus courses has spread in the department. Grassroots stands out from other Phase 1 institutions by its widespread commitment to instructor autonomy. Specifically, instructors of the Precalculus through Calculus sequence do not coordinate their courses and there does not seem to be any widespread desire to develop a coordination system. Nevertheless, the number of instructors committed to educational innovation has grown as the department continues to preferentially hire individuals interested in innovative teaching strategies to improve student success, while simultaneously supporting informal, regular meetings for instructors to come and discuss their teaching practice. Its change story underscores the importance of having formal leaders at both administrative and departmental levels who are committed to hiring personnel who value teaching.

1.2.1. Comparisons of the Six Institutions. In this section we include several tables that represent the different contexts of these six institutions. We hope these tables allow readers to more easily contextualize these change stories, and direct their reading of this volume accordingly.

TABLE 1.1. Institutional context

Chapter	University	Approx. Undergrad. Enrollment ^a	Selectivity ^b	Top three highest (by percentage) ethnicities reported ^c	Research
3	Phased Change	30,000	More selective	White (65%), Hispanic (10%), Nonresident alien (10%)	R1
4	All-In	31,000	More selective	White (35%), Hispanic (30%), Asian (15%)	R2
5	Crossroads	21,500	More selective	White (75%), Nonresident alien (10%), Hispanic (5%)	R1
6	Long-Term	29,000	More selective	White (55%), Nonresident alien (15%), Asian (10%)	R1
7	Critical Response	19,000	Selective	White (35%), Hispanic (25%), Asian (20%)	R1
8	Grassroots	19,000	Selective	White (50%), Hispanic (20%), Black or African American (15%)	R3

^a Rounded to the nearest 500. Data from National Center for Education Statistics (NCES) (2017). Integrated Postsecondary Educational Data System (IPEDS). Department of Education. Office of Educational Research and Improvement.

^b Selectivity is determined by the Carnegie Classification system (Indiana University Center for Postsecondary Research, 2018) which is based on data taken from the 2016-2017 academic year.

^c All percentages are rounded to the nearest 5. Percentages will not sum to 100, as only the top three highest-represented ethnicities are reported.

TABLE 1.2. Departmental context

University	Dept. Size ^a	Percent of Faculty	Percent of Adjuncts	Percent of Postdocs or Visiting Scholars	Percent of Grad. Students
Phased Change	120	21%	20%	3%	56%
All-In	80	37%	20%	0%	43%
Crossroads	130	24%	9%	5%	62%
Long-Term	300	23%	5%	23%	49%
Critical Response	220	30%	8%	3%	59%
Grassroots	70	39%	15%	-	46%

- Data not collected.

To keep the data blinded, all data reported are approximate, with department size rounded to the nearest 10, and percentages to the nearest unit.

^aIncludes number of full-time faculty, adjuncts, postdocs, visiting scholars, and graduate students.

TABLE 1.3. Comparison of Precalculus courses included in reform efforts

University	Typical class size -Small (<45) -Large (45+)	Credit Hours	Main section		Recitations	
			Typical contact time	Typical instructors	Typical contact time	Facilitator
All-In	Large main sections with small recitations	3	150 min.	Adjuncts, faculty	50 min.	Undergrad. learning assistant
Crossroads	Small main sections	5	300 min.	Grad. student instructors (with undergrad. learning assistant support)	N/A	N/A
Long-Term	Small main sections	4	240 min.	Adjuncts, grad. student instructors	N/A	N/A
Critical Response	Large main sections with small recitations	5	150 min.	Adjuncts, faculty	100 min.	Grad. teaching assistant
Grassroots	Small main sections	4	240-260 min.	Adjuncts, faculty	N/A	N/A

TABLE 1.4. Comparison of Calculus 1 & 2 courses included in reform efforts

University	Typical class size -Small (<45) -Large (45+)	Credit Hours	Main section		Recitations	
			Typical contact time	Typical instructors	Typical contact time	Facilitator
Phased Change	Small main sections, w/ small recitations	5	200 min.	Grad. student instructors	50 min.	Grad. teaching assistant with undergrad. learning assistant support
All-In	Large main sections, w/ small recitations	4	180 min.	Adjuncts, faculty	100 min.	Grad. teaching assistant
Crossroads	Large main sections, w/ small recitations	5 (Calc 1) 4 (Calc 2)	150 min. 100 min.	Adjuncts, faculty	150 min.	Grad. teaching assistant, undergrad. teaching assistant
Long-Term	Small main sections	4	240 min.	Adjuncts, faculty, grad. student instructors, and postdocs	N/A	N/A
Critical Response	Large main sections, w/ small recitations	4	150 min.	Adjuncts, faculty	100 min.	Grad. teaching assistant
Grassroots	Small main sections	4	240-260 min.	Adjuncts, faculty	N/A	N/A

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