Actively Learning Mathematics: Toward Departmental Transformation of the Teaching of Undergraduate Calculus[1]

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The overarching goal of the Active Learning in Mathematics Research Action Cluster (ALM RAC) is to improve student success with undergraduate mathematics in Pre-calculus through Calculus 2 (P2C2). The ALM RAC developed curriculum materials that focused on effective teaching practices, which are supported by learning environments that are more conducive to student interaction, reasoning, and problem solving. Gaining faculty buy-in and institutional leadership support was necessary to encourage and, in some cases, fund Graduate Teaching Assistant training aligned with the goals of the project. Moreover, training should include undergraduate learning assistants, employed by many campuses to enhance student experiences with group activities and engagement in mathematical activities and explorations.

Statement of Problem and Aim

Student success in undergraduate mathematics has significant implications regarding student choice of STEM majors and related careers. Even students who do not choose to major in STEM, success in entry-level undergraduate mathematics courses such as calculus can make or break their decision to persist in postsecondary education (Ferrini-Mundy & Graham, 1991; Moreno & Muller, 1999; Rasmussen, Ellis, & Bressoud, 2015; Subramaniam, Cates & Borislava, 2008). Studies of instructional improvements in undergraduate calculus that have been characterized as Active Learning or Inquiry Based Learning have demonstrated improved DFW rates, improved student dispositions towards mathematics, and persistence in taking subsequent courses. Nevertheless, in spite of the accumulation of findings supporting ALM there are institutional challenges that preclude its adoption and sustained support in university mathematics departments (Ganter, 2001).

[1] The RAC Promo Sheet, presented during the opening of the conference to report on current activities of the RAC, can be found after the reference list.
[2] This brief was developed from various sources written collaboratively by multiple members of the ALM RAC. These sources include planning documents, meeting minutes, and circulars developed to help communicate the goals and activities of the ALM RAC.

Lawler, B. R., Ronau, R. N., & Mohr-Schroeder, M. J. (Eds.). (2016). *Proceedings of the fifth annual Mathematics Teacher Education Partnership conference*. Washington, DC: Association of Public Land-grant Universities.

The challenges inherent in institutional change include political, curricular, and cultural features of departments and colleges that resist change and cling to the status quo. Overcoming these challenges requires a commitment to will building, curriculum development, professional development, and seemingly superficial features such as the way tables can be organized in a classroom. Implementing these multiple changes to departmental structures, processes and communication requires complex skills, knowledge, and resources that university faculty are not traditionally motivated nor incentivized to acquire or develop. Teaching calculus in a manner that could be characterized as student-centered is not typically found in tenure and promotion statements, nor is it implied in faculty meetings or departmental communication. However, recent initiatives by the White House Office of Science and Technology Policy and the National Science Foundation in support of active learning in STEM education could have some influence the priorities of universities, mathematics departments and calculus instructors.

How we have addressed the problem to date

Over the past three years, we have worked collaboratively to improve instruction in introductory calculus courses. Initially, with funding support from the Helmsley Charitable Trust. The expansion of our curriculum development and data collection efforts resulted in a number of partners discovering a department commitment to infusing ALM in undergraduate calculus courses can result in early demonstrable improvements in the DFW rates and persistence of students in subsequent courses.

While the contexts across the twelve partner institutions involved in the ALM RAC are quite different, requiring somewhat different approaches to implementing ALM, we have been able to learn from each other's efforts. We have exchanged and co-developed instructional resources, used common measures to document student dispositions, and have regularly discussed the local models used to support learning environments that are more conducive to ALM. At least four campuses adopted the "learning assistant" model that was developed by the University of Colorado Boulder, while West Virginia used Graduate Teaching Assistants in a similar role. Discussions across campuses have helped to clarify the approaches used and have identified the critical role of institutional change in promoting ALM.

The ALM Networked Improvement Community. The members of the ALM RAC understand that challenges inherent in changing instructional practice are, in part, due to systemic nature of teaching in classrooms. The decisions made by an instructor to teach in a particular manner are derived from their interpretation of department goals, the resources allocated to time and space, the design of instructional activities, the opportunities for professional learning, and the department's norms for assessment. Changing classroom practice requires alignment and coordination of multiple parts of the system to support common goals for student learning. Hence, the need for an ALM Networked Improvement Community (ALM NIC) so that one institution is solely responsible for developing a knowledge

base while developing resources for instruction and professional development. Our ALM NIC communicates and documents lessons learned as well as distributes a multitude of resources to reduce the burdens related to preparation of IRB protocols and instructional resources.

Products developed. Two major contributions to resource development have resulted from our efforts in infusing ALM in the P2C2 sequence. Faculty at the University of Nebraska Omaha and University of Colorado Boulder co-developed instructional materials that could be used to replace lessons for calculus topics; and our interest in document shifts in student dispositions resulted in the adaptation, refinement and validation of a student survey.

Tactile + Activities = TACTivities. Inspired by Angie Hodge at a colloquium she facilitated at University of Colorado Boulder, faculty at University of Colorado Boulder partnered with Hodge in the design of TACTivities[3] for calculus. The characteristics of these TACTivities generally included two or more different types of mathematical representations printed on cut cardstock that could be organized to suggest either fulfillment of a complete set, or a categorization scheme that could be justified by students. For example, Figure 1 shows a portion of the Definite Integral Dominos TACTivity. As students touched and moved cards to pair representations, they would discuss their reasons for doing so. Often this would elicit peer feedback either affirming or countering the decision to pair the representations on different sides of the cards.

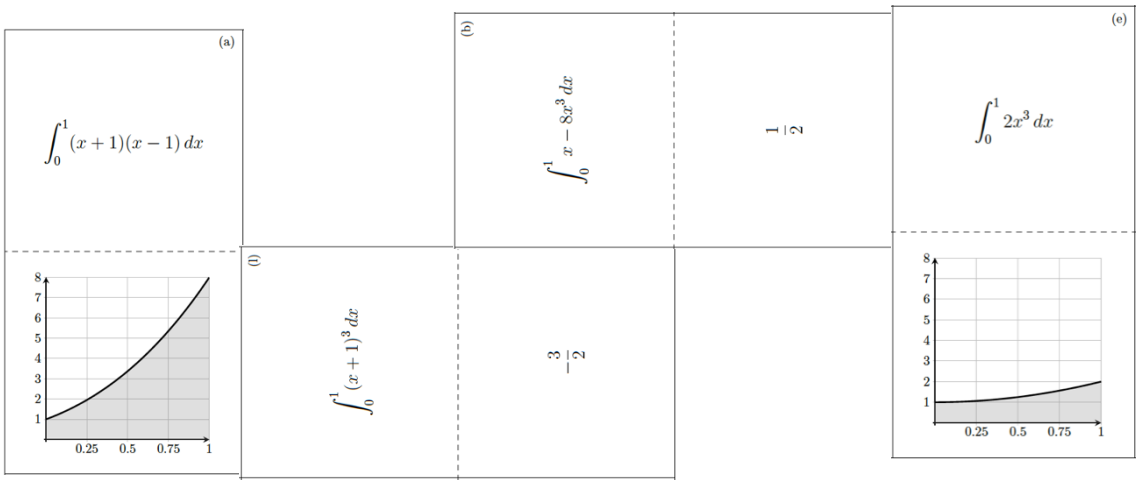

Figure 1: Partial solution of the Definite Integral Domino TACTivity

The other reason to design these TACTivities was that we found they required "low instructional overhead." Often, calculus instructors are graduate students who have limited experience opportunities for professional development in student centered pedagogy. Even at universities where calculus is taught in large lectures there are usually a multitude of recitation

[3] Many resources similar to these have been reviewed, field tested, and published to a publicly available website: math.colorado.edu/activecalc

sections which are typically led by doctoral students. Calculus instructors typically have little experience learning the craft of teaching compared to that secondary mathematics teachers experience in their licensure program. Rather than being able to offer multiple courses to calculus instructors that are connected to field experiences, training at the university was necessarily limited to the weekly one-hour meetings for calculus instructors.

These activities, therefore, were designed to be easy to launch – i.e., they were somewhat intuitive for students as to how to proceed with minimal guidance from the instructor. As instructors used these TACTivities, and as student discussions about the representations emerged, instructors would hear and observe students' ideas and conceptions and use that information as they interacted with groups or facilitated a whole class debrief of the activity.

CALCS instrument. When the ALM RAC formed we recognized one of our primary drivers was students' dispositions towards mathematics. To change student persistence in calculus courses we needed to monitor any shifts in students' attitudes and conceptions of mathematics and what it means to engage in mathematical activity. After reviewing the options available for student mathematics surveys, we decided to use the Colorado Learning Attitudes about Science Survey (which had a mathematics specific version available). Over time as this survey was used we collected enough data to run several factor analyses which informed the inclusion, adaptation and deletion of prompts and thereby strengthened the assessment of several constructs. This adapted survey was renamed the Collegiate Active Learning Calculus Survey (CALCS) instrument and has four main components:

- student attitudes toward mathematics;
- perceptions of the pervasiveness of active learning in class;
- history of previous math courses and intent to take future math courses; and
- Student Assessment of Learning Gains, to serve as a common measure of student content learning that can span different courses and institutions.

The CALCS survey is now a primary data source for the ALM RAC, and all partners are expected to administer this survey at the beginning and the end of the semester. The University of Nebraska Lincoln has been conducting ongoing analysis of data received by partners to continue to monitor the quality of survey as it relates to the intended constructs measured.

Impacts of the ALM RAC

Several of our partners are showing simultaneous improvements to DFW rates and persistence rates in the P2C2 sequence. To date, the ALM RAC has grown from its original five universities to include the following fourteen partner institutions: Auburn University, Cal State Fullerton, Colorado State University, Florida International University, Fresno State University, University of Colorado Boulder, University of Hawaii-Manoa, University of Nebraska Lincoln,

University of Nebraska Omaha, University of South Carolina, San Diego State University, Tuskegee University, West Virginia University and Western Michigan University. Given that our work focuses on changing the teaching of calculus by supporting departmental change, we find the scaling of our group nearly threefold to represent a significant impact on instructors and students. Since the P2C2 sequence involves high enrollment courses, the infusion of ALM in just Calculus 1 could impact over 1000 students each year for just one institution. If all partner institutions implement ALM throughout the P2C2 sequence, the potential number of students who could be impacted by the ALM RAC exceeds 40,000 students each year.

With respect to the Mathematics Teacher Education-Partnership, and the preparation of secondary mathematics teachers, data from the CALCS survey indicates a potential yield rate of 2% of calculus students who are interested in pursuing a teaching license, or approximately 800 students per year. Even though there may be various reasons that students' intentions may shift as they proceed from completing calculus to committing to a major, improving students' persistence rate for course completion and improving the quality of their undergraduate mathematics experience should have a positive impact on mathematics teacher preparation.

Other unexpected impacts of the ALM RAC include influence on other STEM disciplines as many students who complete calculus eventually pursue science or engineering majors, and possibly licensure pathways related to those disciplines. We have also learned of cases in which ALM instructional resources have been shared with science and engineering faculty, building local awareness of active learning initiatives and their potential benefit. Lastly, we know that high school and community college calculus are aware of our work and are using our resources to support ALM implementation in their classrooms.

Summary of Conference Activities

At the 2016 MTE-P Annual Conference we needed to accomplish several goals:

1. To decide on an approach to organize into sub-RACs given the growth of the ALM RAC;
2. To prepare proposals for hosting and arranging site visits to use available Helmsley funding;
3. To develop a list of needs to support local efforts, some which require funding;
4. To support data collection and analysis at new partner institutions; and
5. To discuss the relationship between the awarded NSF IUSE grant, SEMINAL, and the ongoing work of the ALM RAC.

Organizing into sub-RACs. To help manage the growth of the ALM RAC and provide sufficient feedback and support to the needs of specific institutions, we agreed that it was necessary to organize into smaller groups as sub RACs. After deliberating various ways to organize such groups we decided that it would be best to have three course specific groups:

pre-calculus, Calculus 1 and Calculus 2. Even though similar issues are encountered in each course, the curriculum expectations and student enrollment tend to be more similar within each course. The course sub-RACs have agreed to convene virtually every other month starting September 2016.

We also recognized that a permanent sub-RAC structure could limit the interaction between partners and so we also agreed that topical sub-RACs could be convened. Topics relevant to the needs of faculty would be proposed and facilitators would self-nominate to facilitate virtual meetings to discuss challenges and strategies used to address those challenges. To date five topical sub-RACs have been proposed:

- Understanding students' background and interests to support learning
- Lesson study in ALM Calculus I/II
- Professional development for GTA/GRAs
- Revising the CALCS student survey
- Supporting the collection of DFW and persistence data w/ proposals for a data dashboard

We plan to schedule topical sub-RAC meetings every other month starting October 2016.

Organizing site visits. To help the ALM RAC members better understand the similarities and differences among mathematics departments and local contexts, we committed to site visits in fall 2016 and spring 2017. During the conference we developed a table that described for each partner the faculty they should plan on visiting and what they might expect to observe. Our plan is to schedule at least four visits in fall 2016, and we recently constructed a Google Sheet that faculty modify at any time to support site visit planning.

List of local needs. Knowing that efforts are currently underway, we also proposed other options for allocating funds to support local initiatives – for example, jump starting a learning assistant program; partially fund a calculus coordinator; develop additional instructional resources, etc. Even though this is not how Helmsley funds were originally allocated we felt that it would be useful to outline other priorities for funding.

Data collection. The collection of student and instructor data is important to inform progress and necessary revisions to PDSA cycles. However, data collection requires approved IRB protocols and agreement on methods to support reliable data collection across institutions. We discussed how particular methods and incentives could be used to support higher response rates and shared previously approved IRB protocols and instruments to support local research.

Award of NSF IUSE grant. We were awarded a NSF IUSE grant, aka SEMINAL, to study the process of institutionalizing active learning in Pre-calculus through Calculus 2. The project will draw on institutional change research, research on productive undergraduate mathematics learning environments, and on the shared expertise of faculty to study the effect of institutional

culture on mathematics teaching and learning in the P2C2 sequence within and across contexts. ALM RAC members will contribute to this work in multiple ways.

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MTE-Partnership
Solicitation for Participation in the
Active Learning in Mathematics RAC
April 18, 2016

Problem Addressed

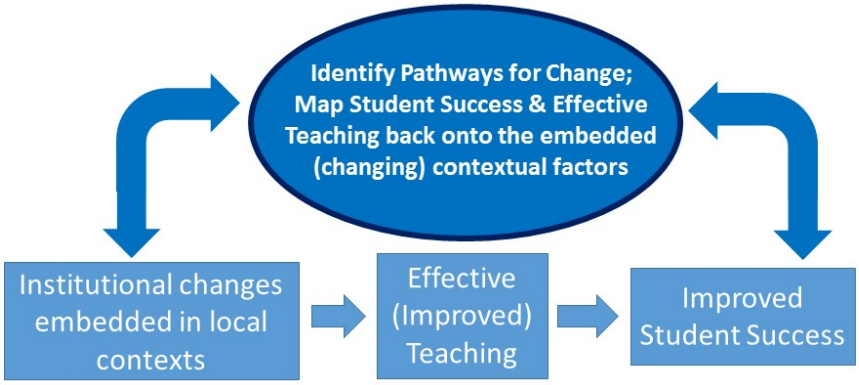
Student success in undergraduate mathematics has significant implications for whether they choose to continue into STEM majors and future related careers. Even for those students who do not choose to major in mathematics, science or engineering, success in entry-level undergraduate mathematics courses such as calculus can make or break their decision to persist in postsecondary education.

The Characteristics of Successful Programs in College Calculus (Bressoud, Carlson, Mesa, & Rasmussen, 2013) showed the percentage of students with grades of D, F or Withdraw ranged from an average of 25% at Ph.D.-granting universities to an average of 37% at regional comprehensive universities. We are committed to improving students' achievement in and dispositions towards mathematics through the use of models for Actively Learning Mathematics.

With respect to the MTEP Guiding Principles, the ALM RAC involves *Commitments by Institutions of Higher Education* through Institutional Focus, Disciplinary Partnerships, and Institutional Support for Faculty. The ALM RAC also addresses the guiding principle of *Candidates' Knowledge and Use of Mathematics* through future candidates' engagement in Mathematical Practices in introductory level undergraduate mathematics courses, to deepen their Knowledge of the Discipline.

General Approach

Our working theory of change is articulated in the following diagram:



The overarching goal is to improve student success with undergraduate mathematics, starting with the Pre-calculus through Calculus 2 sequence (P2C2). This is accomplished through effective teaching practices, which are supported by learning environments that are more conducive to student interaction, reasoning, and problem solving and the use of instructional resources to support ALM. Faculty buy-in and institutional leadership is developed to support Graduate Teaching Assistant training. Also, for many campuses, undergraduate learning assistants are used to support student work with group activities and enhance student engagement in mathematical activity.

Who We Are

Auburn University: Gary Martin, Ulrich Albrecht

Fresno State University: Lance Burger

University of Colorado Boulder: David Webb, Faan Tone Liu, Eric Stade, Robert Tubbs

University of Nebraska Lincoln: Wendy Smith, Judy Walker, Allan Donsig, Yvonne Lai

University of Nebraska Omaha: Angie Hodge, Janice Rech

University of South Carolina: Sean Yee

San Diego State University: Chris Rasmussen, Janet Bowers

Tuskegee University: Lauretta Garrett, Anna Tameru

West Virginia University: Vicki Seeley, Nicole Engelke, Matthew Campbell

Western Michigan University: Tabitha Mingus, Melinda Koelling

Current Progress

Over the past three years, we have worked collaboratively to improve instruction in introductory calculus courses. While the contexts across the ten campuses are quite different, requiring somewhat different approaches to implementing ALM, we have been able to learn from each other's efforts. We have exchanged and co-developed instructional resources, used common measures to document student dispositions, and have regularly discussed the local models used to support learning environments that are more conducive to ALM. At least three campuses adopted the "learning assistant" model used by Colorado, while West Virginia uses Graduate Teaching Assistants in a similar role. Discussions across campuses have helped to clarify the approaches used and have identified the critical role of institutional change in promoting ALM.

Opportunities for Engagement

We are currently utilizing resources from the Helmsley Foundation to coordinate planning meetings to share data collection efforts and develop a research agenda focused on understanding the process of institutional change. A collaborative research grant – Student Engagement in Mathematics through an Institutional Network for Active Learning (SEMINAL) – describes how we intend to better understand how to enact and support institutional change in undergraduate mathematics. SEMINAL will also support future efforts focused on increasing student success and persistence in the pre-Calculus to Calculus 2 (P2C2) sequence, and will promote adoption of ALM among MTEP institutions.

The Active Learning RAC is currently seeking additional partners who are interested in contributing to future research and products, including the use and revision of instructional resources, professional development materials, documented strategies to support instructional change, and the use and improvement of relevant measures to study the impact of these changes (full partner).

We also welcome partners who are interested in field-testing and implementing ALM resources and measures, without the full commitment of contributing to the Active Learning agenda or development of resources (participating partner).