

Name of project lead: Joel Kilty
Campus: Centre College
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I. Project summary

Mathematics plays a pivotal role in the persistence and success of students who aspire to study and work in science, technology, engineering, and mathematics (STEM) fields. While traditional methods of teaching and learning mathematics ostensibly served well for decades, the mathematics community is re-examining and re-envisioning these approaches in response to multiple changing realities, which include: evidence that the standard approach “filters” traditionally under-represented students, extremely different levels of student preparedness, the diverse career and continuing education paths of students, more sophisticated technologies, and access to large data sets that enable more realistic and more relevant applications.

This project sought to further understand the filters that inhibit student persistence and success in mathematics and other STEM disciplines, particularly among under-represented minority, first-generation, low-income, and female students, within the context of small liberal arts colleges located in the southern United States. Beyond exploring these contextual factors, this project made progress in three directions in an effort to effect a positive difference in improving persistence and success. Our work focused on the calculus courses, which serve as a foundational element of undergraduate studies in STEM disciplines.

- Design, implement, and assess a pilot cohort study group model for Calculus I students in Fall 2018.
- Design a “reordering” of topics within the entire calculus sequence during 2018 with planned implementation in Fall 2019.
- Develop faculty proficiency with R and RStudio (an open-source computing software environment widely used in industry and academia) to enable the design and use of teaching modules for calculus in Fall 2018 and beyond.

We had three main goals for our project:

- **Goal 1:** Reduce the real and perceived barriers to the persistence of rising scholars (under-represented minority, first-generation, low-income, and female students) in calculus by (1) exploring the reasons why some persist and others do not and (2) creating improved pathways into and through the calculus sequence by reducing the real and perceived advantages of some students, and mitigating the real and perceived disadvantages of others.
- **Goal 2:** Improve student attitudes regarding both their confidence in their mathematical abilities and the perceived usefulness of mathematics in order to increase the number of rising scholars that persist through the calculus sequence.
- **Goal 3:** Increase collaboration among rising scholars both inside and outside of the classroom thereby creating a stronger sense of community and belonging and increasing student persistence in STEM courses.

We worked to achieve these goals with the following activities:

- **Activity 1:** We held conversations with stakeholder groups and staff in our diversity offices in order to understand the best way to explore and understand (1) barriers to the persistence and success of rising scholars in STEM disciplines at liberal arts colleges and (2) the reasons why some rising scholars choose to persist.

- **Activity 2:** Designed, implemented, and assessed a pilot cohort study group model for Calculus I students in Fall 2018.
- **Activity 3:** Designed a newly envisioned calculus sequence that pays particular attention to establishing educational equity and increasing the incorporation of meaningful examples via technology with an anticipated implementation beginning in Fall 2019.
- **Activity 4:** Introduced all math faculty at Centre and Southwestern to R and RStudio (an open-source computing software environment widely used in industry and academia) to enable the design and use of meaningful examples and teaching modules in the newly envisioned calculus sequence
- **Activity 5:** Administered pre and post attitudinal surveys in all three Calculus courses in Fall 2018 that will serve as baseline data for the calculus curriculum redesign project. We plan to administer these same pre and post surveys once the new sequence starts.

II. Attainment of goals

The first part of Goal 1 involved working to understand the reasons why some rising scholars persist in the calculus sequence while others do not. In order to achieve this goal, we worked with the Associate Vice President for Diversity Initiatives at Centre College, as well as John Wilson, the 2017-2018 Diversity Fellow at Centre College, to determine the best way to attain this information from both current and past students. We had several discussions with Rodmon King and John Wilson before Rodmon left Centre in order to develop a list of potential focus group questions and process for conducting quality focus groups. After Rodmon's departure from Centre we continued this work with Andrea Abrams to significantly narrow the list of focus group questions. In addition, Kilty and McAllister attended a workshop on qualitative data methods to better understand how to structure the focus group questions and how to properly interpret the data. At this point we are close to being able to conduct focus groups and potential follow up surveys, but these will not happen until later in 2019.

Also for Goal 1, we created a daily outline of the entire newly envisioned calculus curriculum and both programs have agreed to work toward implementing this new sequence starting in Fall 2019 for Centre and Fall 2020 for Southwestern. That outline is included as an attachment to this document. As part of the newly envisioned calculus sequence, we were able to remove all precalculus courses and effectively create a three-course sequence for all students (regardless of their backgrounds) interested in completing the sequence at Southwestern or Centre. This sequence was developed to make significant strides towards creating educational equity in the Calculus curriculum. We also have begun conversations regarding transfer credit and placement procedures that will be further developed in Spring 2019. Several years are needed to pilot, adapt, and study these courses before we attain a complete understanding of the efficacy of this new Calculus sequence.

The main measure of success for Goal 1 is whether or not an actionable revised calculus sequence was developed. Despite the challenge of accomplishing such a large and significant curricular change with a large number of potentially impacted allied programs in such a short period of time, we are happy to report that both programs have unanimously agreed to move forward with this curricular change. We plan to work out the implementation details and obtain course approvals in Spring 2019 in order to teach the courses for the first time in Fall 2019.

For Goal 2, we conducted a pre- and post-course attitudinal survey, using the *Attitudes Towards Mathematics Inventory* (ATMI), among all students in the Calculus sequence at both Centre College and Southwestern University in Fall 2018. This 40 question survey is a well-respected and validated tool used to gauge student attitudes towards mathematics. At Centre we collected data on the approximately 145 students who were enrolled in the calculus sequence (Calculus I, Calculus II, and Calculus III); at

Southwestern, we collected data on approximately 120 students. These surveys provide a tangible measure of any change in attitudes after completing the current courses in the sequence. We intend to collect this data in Spring 2019, in the 2019-2020 academic year, and in the 2020-2021 academic year. Thus, we will be able to compare student growth in each of the Calculus courses both before and after the new sequence has been fully implemented and tested. Our hope is that the new sequence will show a positive change in student attitudes towards the usefulness of mathematics, ultimately leading to increased persistence of rising scholars through the calculus sequence. This comparative data will not be available until after the new sequence has been fully implemented.

For Goal 3, we created a Calculus I cohort study group at each university during the Fall 2018 semester. At Centre College, XXX students participated, at some level, in the cohort and at Southwestern XXX students took part. Students were expected to participate in twice weekly meetings where they worked together on their calculus homework and preparing for their exams. In addition to these meetings the students met with their respective cohort mentor as a group at least once a week to discuss best practices for learning, studying, time management skills, and topics related to diversity and inclusion. We developed a thorough manual for the cohort mentor with activities to support these meeting; this manual is included as an appendix to this report.

To measure the efficacy of having students participate in the cohort learning group, these students were surveyed at both the beginning and end of the semester to measure their participation and general interest in mathematics. At Centre College, we observed positive gains for most students in response to queries about (1) finding studying mathematics with other students helpful, (2) feeling less like they were the only person in the mathematics classroom who was struggling, and (3) self-comfort with asking questions of peers in their cohort. Due to faculty travel, the Southwestern University cohort data is not available at this time.

Additionally, we collected some qualitative feedback on how the learning cohort went from both students and faculty mentors. Some comments of interest include:

- “I felt like I needed more people who were also struggling like me to help me become more comfortable.”
- “It was nice to have multiple people work on the same things to bounce ideas off of.”
- “I made more friends to study with, understood more concepts, and become more comfortable with struggling.”

III. Impact of project

While ultimately we believe the biggest impact will be on our students and, in particular, rising scholars, we are not yet at that phase of the project. Thus far, the biggest impact has been on our two math departments. Going through the process of creating the new sequence brought all of us together to work through a difficult task even though we did not fully agree with each other at all times. Being able to see how each other’s departments worked was also extremely helpful and having viewpoints shared from people outside our own departments was critical to helping the process move along and ultimately led to a much stronger direction for the calculus sequence. We believe our departments are stronger for going through this process together, our curricula are stronger, and ultimately our students will be more successful with this new sequence.

The partnership between Centre and Southwestern’s math departments will also have lasting impacts. Centre will begin teaching the new calculus sequence in fall 2019. Due to staffing concerns related to sabbatical leaves, Southwestern will begin teaching the sequence in fall 2020. Centre teaching the sequence first will enable the Southwestern faculty to follow their progress and make updates before beginning the sequence at Southwestern.

The faculty of our departments were also all exposed to the R language and received a manual on incorporating R into Calculus. We now all have R installed on our work machines and have the basic knowledge needed to begin using R in the Calculus classroom when the new sequence starts.

Each of the PIs on the grant also has been impacted by the work for this project. Kilty and McAlister are discussing plans to write a second book that could be used in the second semester of the sequence (they recently published a text with Oxford University Press that will work well for the first semester). Marr was inspired by the inclusion of R and has submitted a grant to NSF to incorporate R across all introductory science and math courses at Southwestern.

Another big impact for our departments is the collection of the baseline attitudinal data for all the current Calculus courses. We will also be able to collect this data in Spring 2019. As the new sequence starts, we will again collect this data and then be able to see over time what effects the new sequence has on student's attitudes and in particular how rising scholars' attitudes may shift based on the new sequence.

We have also presented our initial findings and ideas at two conferences (MathFest organized by the Mathematical Association of America and the AAC&U STEM Conference) during the grant period. Our presentations were very well received and resulted in several great conversations both during the conferences and through email after the conferences. In addition, Kilty and McAllister will be making two presentations on material stemming from grant activities at the Joint Mathematics Meetings in January 2019. We are also beginning to work on an article to submit to the MAA's Focus Magazine regarding our change process.

IV. Consortial (ACS-wide) value of the project

Included with this final report is "A Guiding and Informing Tale for Re-envisioning STEM courses" that can be shared with ACS schools. Within this guide, we outline the major steps we took to arrive at our redesigned sequence. We also provide a set of guiding principles that we used to create our redesigned sequence and these guiding principles can be used at other universities and across disciplines as a starting point for redesigning both individual courses and sequences. This guide can provide not only a practical approach for going about significant curricular change but can also serve as the inspiration needed to take on this type of significant curricular reform.

In addition, this report includes a "learning cohort" mentor manual that has the potential for broad use across ACS institutions. This manual provides a detailed curriculum for a series of discussions with a small group of students on a wide-variety of topics including time management, study-skills, and issues related to diversity and inclusion. The manual is written for a broad audience and could be used in a wide variety of contexts.

V. Lessons Learned

One of the most successful parts of the project was the 2-day workshop we held at Centre College. Almost all of the math faculty from Centre and Southwestern were able to be together for these two days to work on the new sequence and learn a little about using R in the context of Calculus. Being together to work just on this project for these two days was critical to helping us all start to agree on a sequence. It was very helpful to have Dr. Chad Topaz (currently from Williams College, but formerly from Macalester College) join us to help us better understand how this process worked at Macalester. He inspired us to create a set of guiding principles as we continued our work. On Day Two, we were able to create a list of nine guiding principles we used to create the sequence and we made sure that we all agreed with each principle before moving on. By the time we left, we had enough ideas to create a sequence that was very close to the final product we have included here.

One of our biggest challenges was trying to get all the math faculty at both universities to agree to the final sequence. We had a few faculty who had some reservations about a new sequence, but after the workshop those faculty seemed more on board with the ideas. Those faculty were also very helpful in the process as they continually pushed us and asked questions about why certain topics were in certain locations and why we should be pursuing this significant change to our curriculum.

Many obstacles arose from just creating a new sequence. There are issues with transfer credit, phasing the new sequence in, choosing an appropriate textbook, and finding resources for faculty to use to teach the new classes. With each obstacle, we tried to find solutions that would work best for most of the people involved. We still have much to work through in this regard and these efforts will continue in Spring 2019 as we work toward implementation of the new sequence at Centre College in Fall 2019.

One surprise we experienced was the difficulty recruiting students to participate in the pilot cohort study group. We were concerned that we would have a significant number of applications to consider and it would be difficult to figure out who to include in the cohort and who to leave out. After multiple invitations to every student in Calculus I we felt we had enough people interesting in participating to get the cohort running. However, we then had a difficult time getting students to show up to the meeting. At Centre we reopened the cohort again after the first exam to allow any students who felt like they needed the extra support to join and we had a few more interested people join the cohort. As we look towards whether to continue the cohort study group model we need to find better methods to recruit students and a way to incentivize them to continue participating in the group in order to achieve the fullest benefit.

VI. Next Steps

This spring we will decide on course materials to use in each of the three new courses. We will also finalize some of the logistics of offering these new courses: transfer credit, placement, etc. Centre College is ready to teach the new first course in Fall 2019. They will then teach the first two new courses in Spring 2020, and will be teaching only the new sequence across all three classes by Fall 2020. Due to some staffing issues next academic year, Southwestern University will start the new first course in Fall 2020 and will build off the lessons learned from Centre as they phase in the entire new sequence. We will also be able to use our baseline attitudinal data and compare that to attitudinal data as the courses change.

We hope to continue the work regarding understanding the barriers to student success and persistence in STEM fields. We will continue to explore the best ways to gather this information and to help students succeed in Calculus. We will explore whether we should continue with the cohort study group model and if so, how to find sufficient funds to support both the mentor and to incentivize the students to participate.

VII. Feedback/suggestions for the ACS grant program (optional)

While we are much appreciative of the support we have received from the ACS to undertake this important work at our institutions, we offer two specific suggestions that would have positively impacted our grant: (1) being able to move money between different (non-stipend) grant categories and (2) not having caps on how much money can be used on certain expenditures (flights, hotels, food, etc.). There were multiple instances of us having to pay for expenses out of personal funds (particularly travel) despite the fact that we under budget in many other expenses. Kilty and McAllister were fortunate to have some money available through endowed professorship enabling funds to cover some of these overages particularly in regard to the summer workshop. With some increased flexibility, we could have covered all of these expenses through the grant and still finished the grant period with funds to return to the ACS.