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Building Community, Competency, and Creativity in Calculus 2: Summary of a pilot year of project implementation

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Cover Page Footnote

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1 Introduction and Rationale

The COVID-19 pandemic deeply affected students at all levels across the country, both in terms of their mental health (Tasso et al., 2021) and their feelings towards mathematics (Lanius et al., 2022; Murphy et al., 2020). As a result of national trends, and our own understanding of our students need both for mathematical content and community to combat the ongoing isolation of the pandemic, in the academic year 2021-2022, we transitioned our coordinated Calculus 2 courses away from cumulative exams in favor of group projects. Our reasons for this shift centered around the changing student experience of college learning due to COVID-19 and our experiences teaching remotely during the height of the pandemic. In response to these changing conditions, we decided to emphasize group responsibility and building community following the pillars of 'Rehumanizing Mathematics' (Gutiérrez et al., 2018). In this article, we will outline the logistics of these changes to our course, summarize the impacts pulling both from students' feedback and our own experiences as instructors, and make the case for doing a similar, substantive curricular redesign with the goal of teaching to the whole student.

At Smith College, we teach our introductory courses as closely coordinated sections of one class. The instructional team collaborates on assessments, and, in the Fall of 2021, entering our first semester of in-person learning in over a year, we reevaluated our traditional summative assessments. We anticipated that the transition for students to building a community in person would be at least as challenging as learning the material in Calculus 2. In response to this concern, we moved away from traditional exams to a more collaborative, project-based assessment strategy.

Pre-pandemic, the primary assessment tools in the introductory sequence at Smith College were three exams, two during the semester and one during the finals period, each running for two hours. We kept that mode of assessment in the fully remote academic year 2020-2021, but anecdotal feedback highlighted the stress and isolation of online learning. Best practices on trauma-informed pedagogy highlight that when students are in a state of heightened stress response, their cognition and retention drop (Thompson & Carello, 2021). The course design for our Calculus 1 and 2 courses emphasizes welcoming students and making those courses gateways but not gatekeepers for the STEM majors on campus. In light of the changed conditions for student learning, we knew we needed to try something new for our major assessments in Calculus.

2 Learning Objectives and Project Development

We chose Calculus 2 as our testing ground for several reasons. Calculus 2 students have more mathematical experience, which translates to higher levels of independence, but they are still early enough in their careers to be open-minded about the ways they can succeed in a college course. The population in our classes includes many students who have already taken Calculus BC in high school, and keeping those students engaged while also supporting students with less experience is a challenge. The content in Calculus 2 also lends itself to discrete units, with the four major components: integration techniques, areas and volumes, ordinary differential equations, and sequences and series. We also cover the basics of parametric equations and polar coordinates, but as a short unit at the very end of the semester to get students ready for Calculus 3.

Once we identified the four major components of the course, we sought project prompts that would allow the students to be creative, while allowing us to assess what they understood from the unit. For each of the projects, we created a rubric that we shared with the students. We scaffolded each project such that there was a draft of a portion of the project due at least a week before the final draft was due. For each project, we scheduled in-class project days to support the students. We also encouraged the students to work in groups of no more than three to support community building. Below is a summary of each project:

1. Orthogonal Relationship: Using the fact that the sine and cosine functions have an orthogonal relationship with themselves and each other, we explored the notion of the finite Fourier series to approximate different functions. This project relied on integration techniques. This project was based on a homework question that Dr. RB McGee provides to his calculus students at the College of Holy Cross. While less creative than the other projects, this first project provided the students with an experience to extend their knowledge of the usefulness of integration techniques.
2. Design a Chalice/Goblet: Using our understanding of volumes of revolution, we asked the students to design a chalice with specific mathematical requirements for the amount it can hold and the amount of material to manufacture the goblet. We then used Mathematica to render the goblet in 2-D and 3-D. This project provided the students the opportunity to be creative in the design of the chalice, while also giving them the opportunity to practice calculating volumes of revolution and center of mass. This project was based on a project shared with Dr. Price by Dr. Cynthia Weyls, a professor of mathematics at CSU Channel Islands. While computationally difficult, this project allowed the students to be quite creative.
3. How to Solve a Murder: Using our understanding of differential equations, specifically Newton's Law of Cooling, students are tasked with solving a murder. This project was first written by Dr. Price and then edited and rephrased by Dr. Beichman. As a creative project, the students were asked to create a story about what happened in the case they were solving. They provided backstories for the characters and also had an opportunity to include other factors in the case. The use of differential equations in this project supported the students' in-class learning.
4. Convergence Divergence: In this project, students are tasked with creating a flowchart

to help decide if five series in a list of twenty converge or diverge. Each series chosen had to take a unique path through the chart allowing the students to see the practical use of their flowchart, while also providing feedback on ways to edit or make their flowchart more efficient. This project allowed the students to find a way to make a topic that is often difficult for Calculus students to understand and evaluate much easier.

3 Debrief

For faculty members, the projects had a couple of different benefits: they broke up the headlong rush of the schedule, they made the students the central actors in their learning, and they showed different sides of the students. In the middle of each unit, there were two project days in the schedule set aside. Those class days wound up being moments to reset the pace. Most of those project days required minimal preparation, and students took the lead in their individual groups. It was easy for faculty to step in and cover in the event that someone was unable to attend (either due to travel or COVID quarantine). In terms of grading, because the students turned their projects in as a group, the total number of graded items was smaller than for traditional exams. While some projects had more time-consuming parts to grade than others, the humor and creativity on display made sure the grading was never boring or repetitive.

The mechanics of the projects allowed different students to show and develop different skills. Each project had students flexing different muscles, from expository to argumentative writing, reflecting graphs, changing parameters, and filtering ideas from simple to complex. Since these are skills we, as instructors, want students to develop, it makes sense to remove artificial impediments to students actually doing the work. The projects by design make students the primary actors, for good and for ill.

Another consequence of the variety of the projects was the diversity of solutions students provided. Students did not formally present their work on the projects, but the in-class project workdays allowed cross-pollination between groups, and the range of strategies enriched the classroom discussions. The students' enthusiasm for the ideas in the projects led to further work outside of the class. Following the first semester of implementation, a group of students wanted to 3D print their chalices. In Spring 2022, they did just that under the direction of Dr. Beichman as a special studies, culminating in a display of 3D printed chalices in the main school library, just in time for the end of the semester (Beichman, 2022).

As part of the assignment design, we knew we wanted students to reflect on their project experiences as well as balance their weekly workload. On the weeks when a final draft was due, the weekly check-in quiz focused primarily on project reflections, such as "Reflect on the experience of working with a group. What were the pros? What were the cons? How did you distribute the work" "How did you feel starting the project" and "What advice would you give a student starting the project?" Students' responses varied from project to project, but a few themes came through. A common theme for the first project across both semesters was how overwhelming the idea of a project instead of an exam was for students. Despite listing reservations, another common theme was students self-identifying their strengths and ability to be flexible in solving problems.

The second project required students to design their own chalice, giving them significant

free rein in their design choices. Student attitudes at the start of the project were more varied - many were still apprehensive, but more students were simply excited by the chance to design something physical with calculus. Since students picked the curves, their integrals could be very complicated, something many of them reflected on after the project. Students pointed out how their integration skills improved working on the second project, since they were problems they posed for themselves.

As part of the course design, we planned to have the difficulty of the projects drop as we went towards the end of the semester, to contrast with the ways most of the other classes our students are taking would ramp up towards final projects and exams. The third project, in particular, students cited as being much mathematically simpler than the previous two, while also being engaging and fun. The problems in solving the mystery were more open-ended, and the project encouraged both mathematical creativity in setting up assumptions about the scenario and story-telling creativity in arguing for the guilt of the perpetrator.

The final project asked students to organize all the information about convergence tests into a flowchart to decide which test to use. While the end of the semester crush affected students' attitudes about the project, many of them walked away feeling more comfortable with having a process for testing for convergence while also understanding that visualization can be very helpful.

The major themes throughout all the projects related to issues of time management, peer connection, and understanding of the material. Over the two semesters totaling six sections of the course, we saw consistent group engagement, with only one or two instances per semester of problematic group dynamics. In those cases, the instructor worked with the students in the disrupted group to find an appropriate solution moving forward.

One advantage of consistent reflections was that students often made choices on future projects based on their prior experiences. Students would change up their group because of difficult dynamics or time constraints in an earlier project. Students would stay with a group that was formed by happenstance because they found their working styles meshed well, even if they had never spoken until the first day of working on the project. Each project experience built up students' self-perception and allowed for growth mathematically and personally.

4 Assessment

We encourage others to make this change in their courses. It truly has a large impact on the students, not only in your class but in your community. The students interacted with each other and the material in ways that we as experienced faculty had rarely seen. One observable difference was that due to the nature of the first two projects being a bit difficult for the students, once the difficulty was overcome – by understanding how the Fourier series works or rendering the chalice in Mathematica – the students vocally celebrated with each other, enhancing the strength of the community. Once a group had ideas, they were open to supporting other groups with strategies. While most of our students were more comfortable with being assessed through exams, due to the predictability and the time limit, they felt more agency and ownership of the material when asked to push themselves out of their comfort zone with these projects. It gave them the opportunity to tap into their creative

sides rather than tap into their test anxiety.

We all got a chance to see many different sides of the students' creativity. With the first project, although less creative, students found different strategies to solve the integrals they were presented with. The second project tapped into the artistic design side of many of our students. The choices for piecewise functions used to create these volumes of revolution were unique and, thus, no two chalice designs were the same. With the third project, students created their own storyline about the case providing the opportunity for many of our students to use their creative writing skills and their imagination. In the final project, the student could use any medium to create their flow chart and pathways through the flow chart to check for convergence. Students created videos and used Google Slides, or even JamBoards to share their projects. The variety of allowable different mediums fostered a sense of ownership for the students and gave them the freedom to choose what fits best for them. In each project, students were at the center. They got to explore different parts of what it means to be a mathematician — using different mathematical techniques to solve a problem, working with computational tools and programming, analyzing data to formulate hypotheses, and presenting their ideas and conclusions in a way that focuses on the audience.

Our transition from traditional exam-based assessments to project-based learning was eye-opening and impactful. More and more conversations in mathematics pedagogy focus on rehumanizing mathematics (Gutiérrez et al., 2018) and changing the perceptions of mathematics as a competitive field with only one right answer, a perspective framed in white supremacist culture. There is an increased need to teach equitably and to the whole student in the ongoing aftermath of COVID-19. Such teaching does not require diminishing the mathematical complexity or depth of the tasks, but it instead allows us to reach further for connections between content and between people. Our students will enter a workforce more and more dependent on team and group-based initiatives. By keeping our students working and developing knowledge individually, we are under-preparing them for the realities of a world where collaboration and teamwork are the norms, not the exception.

Not every institution operates under the same structures, and the implementation of these types of projects may not be feasible in every place. However, making a substantial change to adapt to the realities of the student experience is both possible and useful both for the student and the instructor. On multiple axes, the projects in Calculus 2 improved student experience and learning, both by adapting to the realities of the student experience post-COVID, allowing them to see themselves in the course and its content, and deepening their understanding of mathematics and themselves as mathematical actors - mathematicians in their own right.

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