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Board 290: Faculty Experiences with Hands-on Models for Calculus Instruction

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Faculty Experiences with Hands-On Models for Calculus Instruction

Abstract

This NSF-IUSE exploration and design project began in Fall 2018 and features cross-disciplinary collaboration between engineering, math, psychology, and math education faculty to develop learning activities with 3D-printed models for integral calculus and engineering statics. We are exploring how such models can scaffold spatial abilities and support learners' development of conceptual understanding and representational competence. The project is addressing these questions through parallel work piloting model-based learning activities in the classroom and by investigating specific attributes of the activities in lab studies and focus groups. To date we have developed and piloted a mature suite of activities covering a variety of topics for both calculus and statics.

After a year of classroom implementation and data collection at the institution where the curriculum was developed, the project team recruited math and engineering faculty from three other colleges to pilot the models starting Fall 2020. The goal of this expansion was to increase sample sizes and diversity for statistical analysis of classroom data and to learn about the experiences of faculty as they integrated the curriculum materials into their own courses. The original vision was for faculty to use the models in face-to-face instruction, but the transition to online modality in response to the COVID-19 pandemic forced a rapid pivot during this expansion that we reported on previously. Faculty participants who chose to continue with the project worked to incorporate the models in parallel with their respective efforts to adapt to online teaching.

This poster focuses on the experiences of the participating math faculty. Ultimately these faculty taught online calculus courses both with and without the models from Fall 2020 through Spring 2022. We conducted pre and post participation interviews and report on their experiences. All participants reported their intention to continue to use the models beyond conclusion of the project and planned to try them in face-to-face instruction. The paper will discuss more details about the interview findings and conclude by making some recommendations for others who may be interested in exploring the use of hands-on models in Calculus instruction.

Introduction

The EMARCS (Engaging with Modeling Activities for Representational Competence in STEM) project is in its fifth (no cost extension) year of a three-year NSF-IUSE exploration and design tier grant. This project is a collaboration between math and engineering faculty at Whatcom Community College working with psychology and math education faculty at Western Washington University, all located in Bellingham, WA. We are working to integrate hands-on learning activities with 3D printed models and manipulatives in Integral Calculus and Engineering Statics instruction. The project emphasizes leveraging these activities to promote conceptual learning and embed spatial skills training. Integral to the work is research to understand how students use the models as learning aids with a goal of using these observations to develop general activity design principles that may be applicable to a wider array of STEM courses. We presented the project rationale, goals, and research questions along with the overall research design in 2020 [1].

Initial work during 2018-19 focused on developing and piloting hands-on calculus models, associated guided activity worksheets, and multiple choice plus explain (MCE) concept questions for Calculus [1] [2]. Our mature collection of eight calculus activities covers the topics of accumulation, centroids (center of mass), volumes with discs/washers, volumes with cylindrical shells, and volumes by slicing.

Figure 1 shows example models for an activity on volumes of revolution. Figure 2 on the next page presents an example MCE concept question. Example activity worksheets and STL files for printing the models are available for download at https://graspthemath.wordpress.com/integral-calculus/. We reported on parallel development work for the Statics models in [3] and [4].

Figure 1. Volume of revolution models used in calculus: assembled model of a revolved parabola (top left), disassembled for investigating the method of washers (top right), collection of models for parabola revolved around x or y axis (bottom left), disassembled for investigating method of shells.

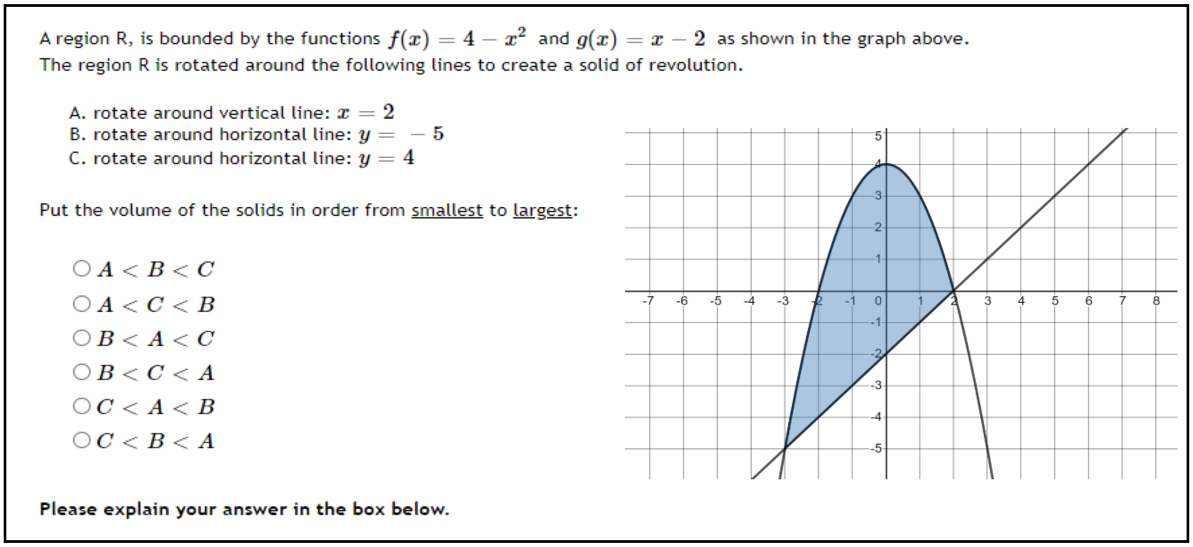

Figure 2. Example multiple-choice plus explain (MCE) concept question for assessing students' understanding of volumes of revolution.

During 2019-20, the project team recruited math and engineering faculty from three other colleges to teach with the models starting Fall 2020. The goal of this expansion was to increase sample sizes and diversity for statistical analysis of classroom data and to learn about the experiences of the faculty as they integrated the curriculum materials into their own courses. The original vision was to kick off the expansion with a one day in-person workshop to introduce participating faculty to the models and curriculum. Then faculty would use the models in face-to-face instruction. The transition to online modality in response to the COVID-19 pandemic forced a rapid pivot during this expansion. We reported in [5] on our experience and student feedback results adapting the curriculum from a platform for collaborative active learning in the face-to-face classroom to individual remote learning at home. Figure 3 shows the kit that we provided to each student in the online sections in which the calculus models were used.

Figure 3. Take-home calculus model kit distributed to students in the intervention sections.

Faculty participants taught course sections with and without the models in multiple sections of asynchronous online calculus courses throughout 2020-2022. We analyzed students' final course grades and pre-post scores on the Purdue Spatial Visualization Test: Rotations (PSVT:R) [6]. This analysis found no significant effect of the presence of the model-based activities leading to increased PSVT:R gains or improved course grades [7]. We would not extend this conclusion to face-to-face implementation, however, due primarily to the compromises made to adapt the curriculum from in-person group learning to asynchronous individual work and inconsistent engagement of the online students with the modeling activities [5].

This paper focuses on the experience of the participating math faculty during this study and explores the following research question: *What challenges do faculty face in adapting the modeling curriculum into their own teaching practice?* This question speaks to a larger challenge in promoting active learning pedagogies in STEM education. Despite compelling broad evidence that active learning is effective [8], and particularly so for historically marginalized student groups [9] [10], wide adoption of these strategies in college level mathematics courses has been slow and inconsistent for a variety of reasons [11].

Results and Discussion

We initially had six math faculty from four different community colleges volunteer to participate in the expansion of the curriculum pilot. All six completed a pre-participation interview with our external evaluation consultant. Their prior experience teaching quarter system Calculus 2: Integral Calculus ranged from twice before to numerous times over 13 years. Participants were asked why they joined the project. Some of the participants joined the project largely due to personal connections with the project leaders, but others expressed varied reasons as illustrated by the example responses listed below.

- *…Knowing that not everybody gets math the same way but that if you do hands-on a different 60% of students will get it and finding varying ways to deliver content so that that students will succeed and appreciate math…*
- *There is a slight financial incentive to participate. And it's not just improving my teaching, I'm getting paid. I don't have a great sense of what I'll be doing yet.*
- *The topic is interesting and it's exploring new ways to help students. I always like to visualize with math. I'm using graphing computers with students so a hands-on tool will help students even better.*
- *I've looked for virtual simulations online for calc and having the models will give me a better way to teach it to my students.*
- *…invited me and I said yes because it sounds interesting, and I like trying new things and I already do a lot of active learning and it sounds like it will turn out to be useful and helpful and I'm always looking for ways to improve my teaching.*

Two questions on the pre-participation interview were designed to gauge their impressions of the usefulness of the models as they understood them. Listed responses are drawn from only the three participants that were able to continue with the pilot. We lost three of the six participants due to changes in teaching assignments as departments adjusted to the online learning transition.

In summary, these responses convey a general sense that all three participants saw potential in using the models as a learning aid to help address common points of student confusion and struggle in integral calculus.

What do students struggle with in the course?

- *They fight with the washers and the shells knowing direction integration. Any time there are more than three things that they have to do from question to answer, they don't follow it conceptually or think about why it looks like that. The mechanical part of multi-step techniques are also something they struggle with.*
- *I think when we learn about volume and solids of revolution (the last 3rd of the course) a lot of students have trouble visualizing it.*
- *Solids of revolution. A lot of students can't picture what is going on and they don't have visual abilities to even know what to draw.*

What do you think might be the benefits of using models?

- *There are ways of using models for different things and it makes it more concrete. If you don't know why you're doing something, that's where the gap is.*
- *Being able to physically manipulate the model will help. Memorizing the formulas doesn't build a solid understanding.*
- *Being able to help students visualize and the fact that the students can take them apart. Seeing all of the different pieces at once. And how they fit together.*

There was also some apprehension about using the models in online courses in the context of the pandemic as indicated by the responses quoted below in response to the question: "Going forward, what do you anticipate might be some of the challenges to doing this work in your context?"

- *In face-to-face class there is always push back from a student who doesn't like to work in groups. I think there might be a little push back from students. How robust and strong are the models? Are they going to break? Is there anybody for whom this will hurt their understanding and muddy the waters and making their understanding worse? And how much time will it take?*
- *The fact that it's online, so distributing the models. For about 10% of the students this will be an added burden. We have big (safety) hoops for anybody coming to campus so working through the bureaucracy. It's going to be challenging for my students to do this at home on their own. It would be easier if they could work together with a group of others.*
- *Because it's online that will present a challenge. Right now, I have videos and worksheets, but I don't know if the students are doing them. It will be hard to know how much students are taking advantage of what they are given. Logistically, getting the students the models and getting them to pick them up could also be a challenge.*

We provided all three faculty with the model kits to distribute to students and the same activity worksheets that we developed for online use of the models. Model kits were distributed to students by making them available for pick-up at the respective campus bookstores. They worked to incorporate the activities and models into their teaching in the midst of ongoing efforts to rapidly adapt to the online modality that was new to all of them. All three faculty had multiple terms teaching with the models during the pilot.

Post-Participation Interview Results

The faculty participants found their own ways to use the models and did not necessarily use the provided curriculum. One faculty member created videos in which they provided an example of how to use the models: they wrote out a problem, and then walked the students through how to use the model and make sense of what the model was demonstrating. They also made a video of what was in the kits. This individual didn't use the worksheets at all.

Another faculty member used the models at the end of the course in Weeks 8 and 9. They also made a video to show their students how to unwrap and use the models. For the second exam in this course, the students came to campus to get the models; the instructor demonstrated examples of solving problems using the models; and then the students solved the homework problems related to those the instructor modeled. This instructor also tried having the students use the models during group work on Zoom.

Two of the faculty reported that they benefited from using the models as much if not more than their students as illustrated by the following comments:

- *I have learned so much more by using the models. The benefits are as much, if not more for the teachers because you get experience asking, "but why?" You can anticipate the students' questions and it makes your explanation better.*
- *I learned the calc more deeply because I had to play with the models to figure out how I wanted the students to use them. I had to take them apart and drill deeper so I could give the students adequate guidance. I learned that if you put your mind to it, you can probably make physical models for any concept. It would never have occurred to me to make a model of 3d rotational force.*

Use of the models also affected participants' thinking on the importance of visualization in math:

- *I used to think it was better for students to not visualize the math but that has gotten totally reversed. Students benefit more from having a physical model to be able to visualize. Before, I thought they should do the mathematics without the picture. I think you practice with the model and then get to the place where you no longer need it.*
- *I learned that the models are cool and helpful. Having the models, and spending time myself on the connections between the paper and the 3D models made me realize that instructors can take for granted that students will be able to visualize. I learned that having the actual [physical] models is more useful.*

The faculty reported decidedly mixed results in terms of student feedback on the models and attributed this largely to not being in person. This finding is consistent with what we reported previously with regards to the transition to using the models for online courses [5]. They did share some positive anecdotes. Some students shared with the instructors that the models really helped them:

> *Students have written to say that they understood the concepts better because they had the models so if that's the case then why would you ever stop using them.*

While other students liked it when the instructor used the models:

> *Many said they liked ME doing examples with the models but they didn't get a lot of extra value having the models themselves but that could have been different if we were in person. Others said it was nice and helped them visualize. Only 1-2 said they weren't helpful at all. Just me using them was enough.*

One faculty member shared an anecdote involving the students' use of models

> *There was a group of students who would go into the math study center and one of the students hadn't opened her model kit, and she was having trouble visualizing the problem. She was blown away that [when she used the model] she could visualize it, and she thought it was amazing.*

None of the faculty shared challenges they had with incorporating the models into their teaching, but all expressed challenges associated with distribution of the kits in the context of the pandemic learning environment and uncertainty about how much some of the students engaged with the models, noting that some students never picked their kits up.

> *It was hard to figure out how to get the students the models in my college. It was a bit of a process to fit this into the existing process for our lab kits. Getting students to actually pick them up was hard and some students never got them. The ones that did pick them up mostly didn't give the models back. My college didn't have a system for getting the models back. I gave up on that and I still have a lot of models.*

All instructors said they would continue to use the models when teaching Calculus 2 in person. One would "definitely" make use of them next time. While another doesn't plan to teach the course again, he would use the models if he was teaching it again in person. A third faculty member said that they would use the models if the class was in person. The logistics of getting the models to the students who are remote is too challenging for two faculty members to want to incorporate the models into online courses. In the future, one instructor would like to allow time for the students to play with the models first, before using them for instruction.

> *I think I could improve the activities that I give my students if I could watch them play with the models first. What do the students do with the models before I ask them to use the models to solve a problem? I want to use the models by first experiencing the students' reactions to the models.*

Conclusion

Our findings can be summarized as follows. Faculty had a variety of reasons and motivations for choosing to participate, but generally saw potential for the models to be useful learning aids for their students when first introduced to the curriculum. The participants incorporated the models in different ways and did not rely exclusively on the activity worksheets and supporting curriculum supplied by the project team. Faculty reported that using the models deepened their own understanding of core concepts and increased appreciation of the connection between spatial visualization and learning calculus concepts. They reported challenges with respect to distributing the models and varying levels of student engagement with the activities. This interview data does provide more context to the inconclusive student assessment results we reported in [5].

While the three faculty that are the subjects of this paper form a small sample likely not reflective of college mathematics faculty in general with regards to their willingness to implement active learning strategies with the provided models, we note that all three faculty saw promise in the curriculum for addressing common student challenges and subsequently plan to incorporate the models into their future face-to-face Calculus 2 courses. It is also important to note that this work took place at the height of the pandemic-enforced remote learning environment and associated shifting sands of student enrollment patterns and engagement levels.

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