ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE
Paper ID #36968

A sustainable model to structurally improve outcomes in Math courses for Engineering students.

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A sustainable model to structurally improve outcomes in math courses for engineering students

Introduction

Incorporating active learning pedagogies to increase student learning has gained increasing interest and attention in higher education in the last decade. In STEM, many introductory courses have been completely redesigned to embed active learning. At the University of Virginia (UVA), the Applied Mathematics (APMA) program has progressively moved to a model with near-peer learning, which is heavily based on the participation of Undergraduate Teaching Assistants (UTAs). In this new role, our UTAs need to grasp 1) foundational principles of learning and 2) effective methods for interacting with students. We have designed a path to guide UTAs to become the best possible resource for our students, and at the same time, to provide UTAs with a meaningful personal experience.

Background

The main reason we had to start active learning, was need for innovation. Our program in the Engineering School (E-School) had been left idle for about 20 years, since the APMA department was eliminated in early '90. Applied Math (APMA) courses were taught either by faculty from other Engineering departments as an "APMA-tax" to the Dean, or outsourced to the Math department, in the College of Arts and Science. Nobody had interest or incentive to change anything. Finally, in 2011/2012, a new group of APMA faculties was assembled, and we started an extensive revision of the way we were delivering math courses to our undergraduate engineering students. Even though the engineering school did not urge us for innovation, we could not turn a blind eye to how the teaching and learning environment was changing around us:

- Emerging new technologies
- Open-source online homework systems
- Changes in demographic in the engineering school, with increasing female enrollment. UVA E-School has one of the highest ratio of female-to-male students in US: 34%.
- A slow but steady growth of underrepresented minorities.

In addition, engineering schools change their approach towards students by shifting from a weeding system to an inclusive one: from "*sorry you are not good enough for us*" to "*how can I support you so that you can make it*" [1]. All the above (and more), brought us to abandon the rigid 1980's lecture style for a hybrid model, with mini-lectures and in-class group work. This plan required a full redesign of all the material, and it was a combined effort with the contribution of several of our faculty. Anyway, just adapting the material would have been irrelevant if we had not realized that we needed a new learning environment for our students.

The Rise of UTAs

Our typical class size is about 50. In-class activities are based on 1) group work among students, 2) interaction between students and the instructor. Since one instructor cannot reach out to all

groups (about 10-12) at the same time, we needed in-class "support" to facilitate in-class group work. Indeed, if we cannot be there when students get stuck or have a question, the utility of the model is in question. To have more bandwidth in class, we hired several undergraduate students to help the instructor. We selected them by the usual channels: students, who are interested, and have successfully completed the course, apply to be "graders". Then we asked whether they would be willing to, besides grading, attend class meetings and help students during group work in understanding ideas and mathematical processes behind the problems. Many of them were enthusiastic, but despite of their motivation and enthusiasm they soon realized that knowing the material and having performed well in the course would not mean they could communicate their knowledge effectively to their almost-peer students. These 20-year-old UTAs had no teaching experience, but were brilliant and very passionate, and we thought they could greatly benefit from any additional support in their training.

This becomes an urgent issue when more and more UTAs were embedded in many of our multi-sectional courses. On a small scale, it is easy to find very good students as UTAs. At first, we were teaching only 2 sections with this method, and it was easy to select 2-3 students extremely advanced, top 5%, with many additional personal skills beyond math. This is not any more sustainable when many sections are involved, and about 40-50 UTAs are needed every semester. We realized UTAs are a fundamental part of the model, cannot be given for granted, and need to be trained. This has been a critical milestone in our project.

Our first form of training was *in-house:* our first UTAs were training new ones while in the classroom, either by example, or by word-of-mouth. Unfortunately, this process turned out to be too volatile and random, depending on the availability of exceptional students who can really become leaders in one semester, and, even with them, each of them would bring in just their personal experience. Moreover, even great UTAs would just graduate after few semesters, and leave.

The Progression of UTA's Role

The role of the UTAs grew and evolved progressively, and almost spontaneously, over the first semesters. In a classroom setting, with several groups working on an assignment, we envisioned the instructor to move from one group to another, devoting their attention to 4-5 students at time, while UTAs would be the first "temporary" responders to other groups, until the instructor could move to that group. In reality, UTAs were perceived as "full" responders from the very beginning. We, instructors, like to think that this was because of our regular meetings with UTAs to discuss the material of the next lectures, highlighting critical steps and traps, and anticipating students' questions. More notably, UTAs had a solid grasp of the material, they could address students' questions from students' point of view and had recently gone through the same learning process as students. They knew exactly what students' questions were about. Quite often, students felt more comfortable and less intimidated at asking questions to UTAs, sometimes preferring UTAs to instructors. As UTAs are not involved with grading exams and midterms, but only with grading worksheets (~10% of the final grade), students do not perceive them with the authority to impact grades. UTAs are considered just as tutors in the classroom. This perception, the age proximity, and the physical proximity of being in the same room for many hours a semester, creates a connection between students and UTAs that goes beyond the course. UTAs

become role models for students who want to major in the same engineering field, are asked questions about more advanced courses, core courses, electives, and more in general about college life.

Over the years, the UTAs' role has expanded to include several activities outside class: they now hold special office hours before midterms and exams, as review sessions, create videos for students where they show solutions to complex problems, or review basic math material from previous courses, e.g. partial fractions in an Ordinary Differential Equation course. Instructors work with them to set up course content in our learning management system, such as videos, images, links, improving the quality of the online course material. With tools such as Discord, or Slack, our students can easily reach out to UTAs almost on demand, while they are both logged on online platforms. Quite often the conversation is a-simple-question and a-simple-answer which then is available to and could benefit everyone on the channel. UTAs are fully integrated into our course, and, as of now, our students expect to have UTAs in their Applied Mathematics courses as a default.

The UTA Course

Our original goal was to support our students within our active-learning classrooms, but it became immediately evident that UTAs' experience, skills, and confidence were also greatly enhanced. After discussions and feedback from UTAs, we realized they were going through an educational process themselves, being exposed to something truly new to them: learning how to teach. Some were enthusiastic, others a bit confused, or unsure of which would be best practices, seriously elaborating on their class interactions, and trying to understand deeper their roles as supporters in learning. This whole process had an impact on them as students, on their own learning, because they were thinking for the first time about how the learning process works. With all this, we realized UTAs had too much on their plate, and we needed to step in to provide tools and mindset for them to be successful in this transitional process from students to educators.

Since our institution has a university wide center supporting teaching related activities, The Center for Teaching Excellence [CTE], we joined up with their faculty to design a "Teaching Methods" course for our UTAs and tailored specifically for Applied Mathematics. This program got finally started when we received a 2-year grant from the Jefferson Trust which was matched by the Provost, the School of Engineering and CTE. The funding supported two postdocs scholar situated in the CTE working across schools. The postdocs worked with Lindsay Wheeler and Lynn Mandeltort at CTE and with the authors, to design and then teach the first runs of the "Teaching Methods" course starting in Fall 2017. Over the years, the course has been modified to embed feedback and changes suggested by students, UTAs, faculty, and even the Dean's office. It is important to mention that the Dean realized the value of UTAs as first "soldiers on the field" to detect any sign of stress or risk in students, and to report them to faculty for further steps.

In its last version, the goal of the course is to equip undergraduate and graduate teaching assistants with the skills and mindset to support students learning as well as their own learning. Students who complete the course are expected to be able to

- use student data to inform teaching,
- connect and apply relevant education theory and literature to teaching experience,
- develop the practice of reflecting on their social positioning, learning habits, and professional development, and intersection thereof,
- see the values of pedagogical skills in the workplace.

The course meets just once a week for an hour, but the TAs come away with a fantastic skill set that benefits themselves, their students, and the faculty with whom they work. The schedule of the latest version of the course and a sample course project are provided in the Appendices section (see Appendix A and B).

There exists a very large and diverse body of literature documenting the value of training and/or professional development for teaching assistants across disciplines in higher education. In the bibliography we include few references [2],[3],[4], [6].

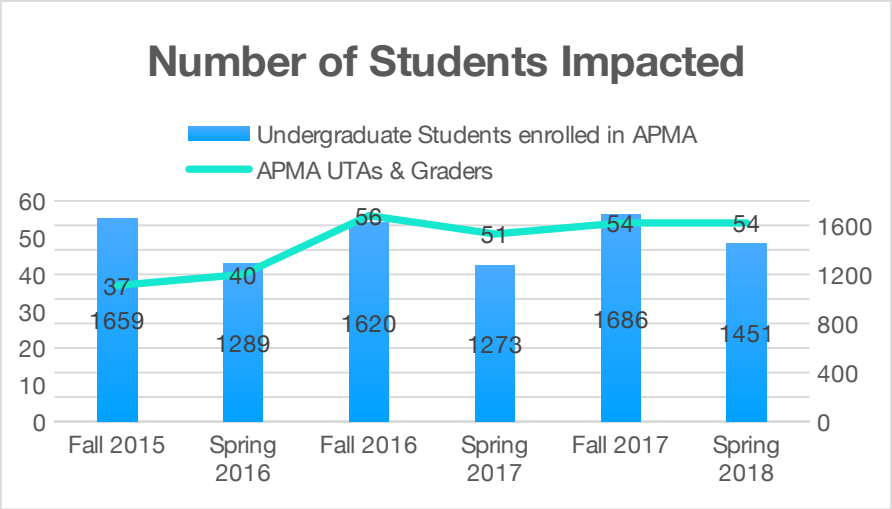
The Learning Environment

Our UTAs, and graduate TAs, are an essential component of the learning environment available to our students. For completeness, we describe here the full learning environment, of which trained UTAs are a clinging element, being present in class, and outside of class. In Applied Mathematics, we offer a physical and virtual learning environment where team discussion and group work is promoted; we have a large room with whiteboards, next to faculty offices, where teaching assistants (including UTAs) hold office hours in the afternoons, which is available for students to meet and work on assignments 6 days a week; multiple resources are available online on demand, including extensive opportunities to practice; every weekday several people, instructors, graduate teaching assistants, and undergraduate teaching assistants are available for support almost in real time.

We believe this model, combined with the in-class daily deliverables, determines a continuous engagement for students, promotes a distributed effort, and reduces assignments pressure.

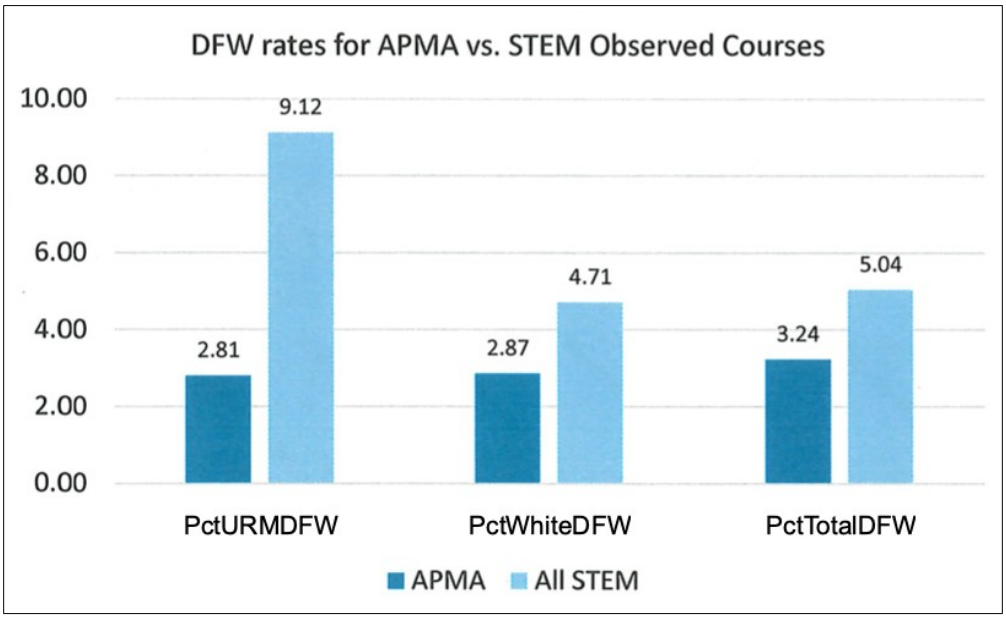
Results/Outcomes

The presence of UTAs in class has become the new standard in Applied Math courses at the University of Virginia. As all our instructors are engaged with several UTAs, they have recognized the fundamental value of the “Teaching Methods” course in preparing and supporting UTAs. As recently as Fall 2021, our department has voted for the course to become a requirement for all students who want to be UTAs or GTAs for Applied Mathematics. Students take this course concurrently to their first semester as UTA or GTA. Here is a summary of the number of students impacted by the model from Fall 2015 to Spring 2018.

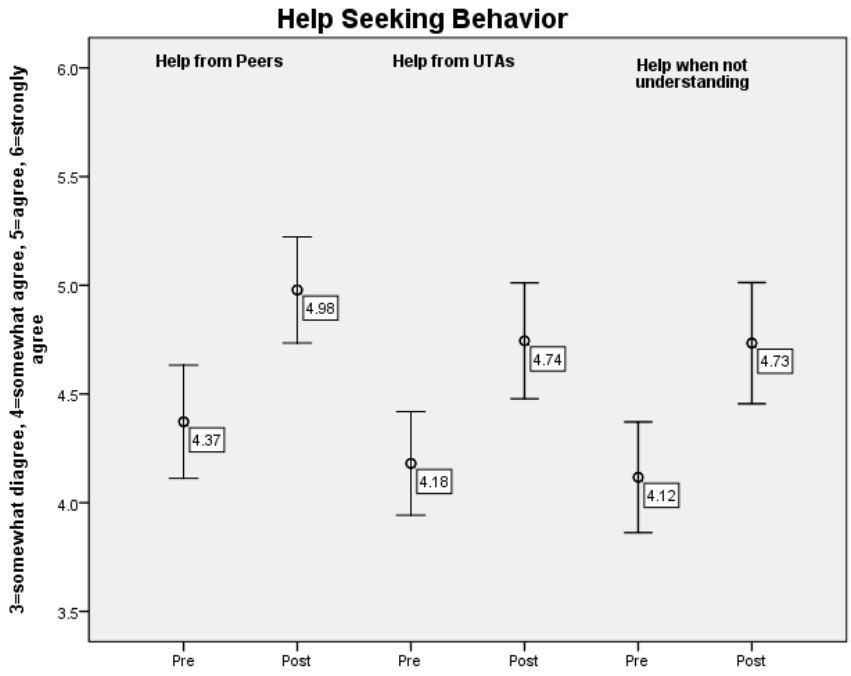


As reported above, a combination of external resources did support our first 3 years. After funding expired, the teaching of the course, and its more recent evolution, has been provided by Lynn Mandeltort from CTE as part of her engagement with the Engineering School. Following the vote by the department, Applied Mathematics will take over the teaching of this course, and a faculty with interest in education will be the main instructor from now on. We expect the course to adapt to new needs and/or requests as we will face them, but at this stage the course is quite well defined, and ready, for interested colleagues, to be explored and possibly copied.

We have some preliminary findings related to this educational model. The graph below shows the percentage of DFW rates for 2016-2017 after the implementation of the UTA model, compared with other STEM observed courses [6]. There are many factors that could play a role in the lower DFW rates for APMA courses, such as the shift of instructional practices, we do believe that the use of UTAs in the classroom contributed positively to this result.



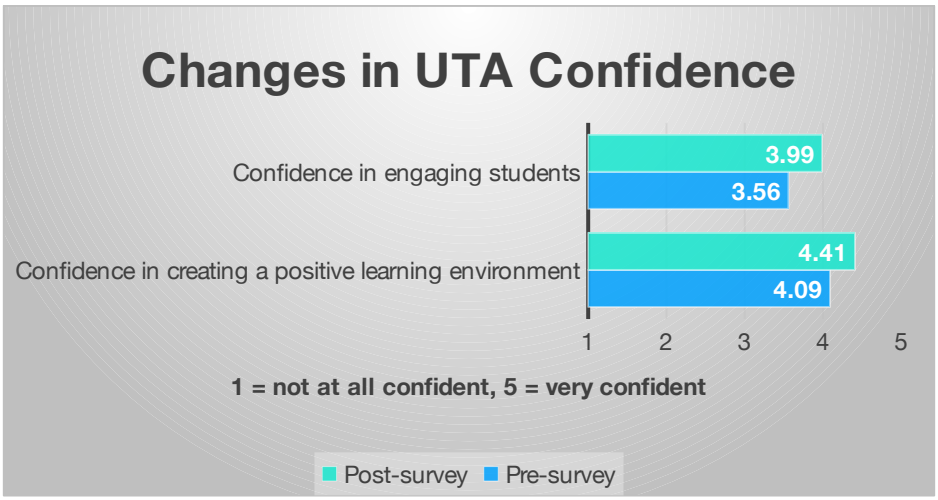
In addition, students' help-seeking behaviors significantly improved, as shown in the following graph [5]:



As examples of non-numerical evidence, we report that UTAs have almost superseded GTAs in one-to-one interactions with students, and, exceptionally, we have even had UTA in a Graduate course as support for software group projects. At this time, undergraduate courses that include UTAs are more advanced, in terms of innovative pedagogies implemented, than our graduate courses.

We also have direct feedback from UTAs, as they report improved knowledge and understanding in their own mathematics, increased confidence in leading the conversation in a group and in addressing technical explanations to an audience, awareness of pedagogical tools and techniques, and knowledge of group dynamics. Many of these skills are explicitly mentioned in graduate school applications, and we feel our UTAs get an advantage at it.

UTAs confidence in their ability to create a safe learning environment for students significantly improved across the semester ($z=-2.156$, $p=.031$), as did their confidence in being able to engage students in learning ($z=-2.362$, $p=.018$) [5]. Moreover, there has been a significant increase in interest in Applied Mathematics, as 50% of students pursuing an Applied Mathematics minor are now UTAs.



On a faculty side, the "Teaching Methods" course has increased the level of pedagogical awareness of all our faculty in Applied Mathematics, since all their UTAs and GTAs must take the course. This has facilitated the adoption of tools across courses.

Future Evolution

Graduate students do not participate in our in-class activities due to time conflict with our courses and their courses or research labs. Nevertheless, we require them to take the "Teaching Methods" course, as they interact in person with students during office hours. Due to the features of the educational model, students are likely to go to GTAs' office hours in groups, or just spontaneously cluster together in the APMA workshop, so that GTAs find themselves dealing with a "small" class of students. There is also a key difference between GTAs and UTAs: our GTAs mostly come from other institutions, and do not know the undergraduate universe here. They need to adapt to the school more than UTAs, and the course is helping them in this respect. As a possible expansion of this program, we are considering an educational path for graduate students that would boost their teaching skills. At this time, graduate students at our Engineering School do not get training to teach, as they devote all their time to research, and their teaching practice is limited to office hours. Despite that, several graduate students are concerned that little exposure to teaching may impact their chances to get a job in academia. We would like to cast a program that, starting from our "Teaching Methods" course, could lead them to co-teach a course together with a faculty, and finally bring them to teach their own course before graduating. This is a path that is intended for post-docs interested in acquiring teaching expertise as well.

TAs' comments

We report here selected feedback from students who took the "Teaching Methods" course [5].

Comment 1:
Working as an Undergraduate Teaching Assistant for APMA 2130 for the first time, there has been a lot that I have learned within the first month of this semester. I quickly realized that

although I did well in the course when I took it, this did not mean I would instantly be this perfect TA that I thought I would be. It was almost as if there was a roadblock between the ideas formulating in my mind and the words that I was trying to speak. I immediately began to wonder how well I would actually perform as a TA and what steps I would have to take to be the kind of TA I envisioned myself being

Comment 2:
Looking back, I think that the most important thing I have learned in this class is the key to teaching: confidence. Personally, this was something that I struggled with at the outset of the class. I felt that I did not understand the material well enough to be teaching it; however, after obtaining feedback from students and learning that I was truly helping them, I became a great deal more confident and able to focus all of my energy on helping students, instead of getting caught up in nervousness. Furthermore, since I would like to have some sort of teaching component in my future career, I have learned the larger importance of confidence. Being nervous or insecure in one's ability to teach something they are obviously qualified to teach (otherwise they would not be chosen for the role) can only hurt their performance. Thus, in really anything I do, I have learned to recognize that I am doing it for a reason and deserve to be there – and this recognition really helps me be more confident. The discussion we had in class regarding confidence really helped me employ this mindset.

Comment 3:
During our discussion on metacognition, we first thought about how being metacognitive has helped us out in our college career so far. While I had not really thought about it prior to our discussion, I can definitely recognize how useful it is to be aware of the way you think and to be able to evaluate where you really are in a class. For example, being able to recognize areas of weakness in a subject is incredibly beneficial as it allows you to seek the right help and to plan accordingly for future exams. We learned in class that being metacognitive can sometimes be difficult to some of our students and it is important to try and get the students to reflect about where they are at in the class. Getting students to think about the way they think can allow them to perform better in the class and understand the areas in which they are strong in and those that they are weak in.

Comment 4:
I graduate after next semester and will start a job where I will be testing software. I hope to be able to use my knowledge gained from being a TA to be able to interact beneficially and successfully with teammates and supervisors. By knowing how to facilitate working in a group, I believe I can enhance my work environment. Even though I have a job in the industry for next year, I ultimately want to become a teacher of high school math. The experiences that I have gone through TA'ing have helped me realize what types of situations I may encounter as a teacher and understand how to react to them. When I teach in the future, I can apply the knowledge learned in this class and make sure to always allow students to think first, reflect on my own teaching, and motivate my students properly

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APPENDICES

Appendix A: Course Schedule Fall 2021

Date	Topic	Assignments due *before* meeting
08/30	*No class meeting while TA hiring is still underway!*	
09/06 (our first day)	What is learning? How does this relate to teaching?	• Read syllabus • Complete course survey
09/13	How do we effectively grade student work? (Prof. Guadagni)	• Post on Discussion board • Private reflection #1 due
09/20	How can we motivate students to learn?	• Reading • Discussion post based on reading
09/27	What are ways to interact with students that promote learning?	• Discussion post • (Optional) - read Ch. 8 of *Teaching At Its Best*
10/04	What questioning strategies can we use to engage students?	• Discussion post • Work on mid-semester project
10/11	How do I deal with common class scenarios?	• Discussion post- try questioning strategy • Mid semester project draft analysis • Mid-semester project peer feedback
10/18	*Reading day. No class meeting.*	
10/25	How can we identify and help distressed students?	• Discussion post
11/01	How can we respond to common teaching scenarios?	• Video and Discussion post
11/08	How can we help students with metacognition?	• Prep final project (contact your instructor)
11/15	How can we teach a diverse group of learners?	• N/A
11/22	Revisiting motivation. What power do TAs have?	• Final project outline DUE • Read suggestions from email update (TBD)

Appendix B: Final Project

Purpose

This assignment is a chance to apply and showcase what you've learned in this course. As such, think about how you can demonstrate progress toward the course learning objectives.

Task: Two Options[1]

1. Video lesson

A 5 - 8 minute video in which you demonstrate a problem solving procedure or review a concept that commonly challenges students in this course (the course you TA for). As always you are invited to be creative with your approach. I am happy to help you think through ideas.

The video lesson should fit several criteria: background knowledge, common mistakes, student perspective, problem solving, explanation, video quality, timing. Read about each of these in the rubric (will also be uploaded to iRubric) and see an example below.

2. Review session

A lesson plan for a ~60 minute review session for your course in which you showcase what you've learned in the Teaching Methods course. As always you are invited to be creative with your approach.

The review session is a detailed lesson plan that describes the specific sequence of actions you will take to support students in reviewing for their assessments. The criteria include: motivation (connecting concepts), common mistakes, visuals/slides, activities, timing. Read more about each of these in the rubric and see an example below.

Deadlines

- By **Monday November 22,** you should contact the instructor of your math course to determine how and when you will share/present your project. You may also wish to ask them for suggestions on the topic and/or style of project (see Task above).
- By **Monday November 22** you should submit your project outline on Collab including the date and modality determined above.
    - *For the outline, include the following:*
        - *What kind of project will you choose?*
        - *What is your plan for contacting the instructor of your course?*
        - *What is the topic and why are you choosing it?*

1 As always, you are invited to be creative with your approach! Please contact Prof. Mandeltort if you'd like to discuss additional options.

        - *What common misconceptions do students have related to this topic?*
        - *What activities/demonstrations/technology will your project feature?*
        - *Describe an approximate order of the content for your project and what tools/tech you will use to engage students.*
        - *How will you incorporate what you've learned in the Teaching Methods course? Be specific.*
- By **Monday December 13**, you should submit your completed project on Collab. Your scheduled time for presenting/sharing your project with your math class may be a different date-- keep the goals of this assignment in mind: it should useful for your students, and we (you and I) should be able to discuss it for your end of semester reflection.

Resources to help you

Video recording tools

- Panopto
- Voicethread
- Zoom recordings, followed by Panopto, Kaltura, or other editing/hosting
- ...many others! I'm happy to discuss more options with you.

Tips for making quality videos

- Effective educational videos (webpage) - this page is a great summary of research and practical suggestions for making educational videos. Start with this one for sure.
- A 5-Step Guide to Making Your Own Instructional Videos (webpage)
- Performing for simple videos (youtube)