TRANSFORMING CALCULUS COURSES WITH CUTTING-EDGE VIDEO RECORDING AND EDITING TECHNOLOGIES – A CASE STUDY

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Introduction to the Problem

Calculus is a fundamental course for science, technology, engineering, and mathematics (STEM) majors, with over 300,000 students taking the course in fall 2010 across the U.S (Bressoud, Carlson, Mesa, & Rasmussen, 2013). As a critical course for these students' success, it is imperative that this course be taught in a way to support students' understanding of the concepts. Since calculus is a gate-way course for STEM majors, the quality of calculus instruction has been a source of national concern (Seymour & Hewitt, 1997).

Unfortunately, U.S. colleges and universities are struggling with high attrition and failure rates in this course (Hagman, Johnson, & Fosdick, 2017). Although potentially many reasons exist to explain these issues, two potential reasons have been identified in the literature. First, graduate teaching assistants (GTAs), mostly Ph.D. or M.Sc. students, assigned to the unique role of a recitation instructor may not be receiving the specialized training needed to effectively lead a calculus recitation (Belnap J. , 2005). In fact, they typically have significant training in their field of research but little preparation to teach (Kung & Speer, 2009; Speer, Gutmann, & Murphy, 2005). In fact, GTAs express concerns about the insufficiency of information covered in the course and the lack of opportunities to practice learned pedagogy (Belnap, J., 2005). On the other hand, it is found that of the 23 PhD-granting universities surveyed, 39% of the GTAs were discussion or recitation leaders (Belnap, J., 2005; Belnap & Allred, 2009).

Not surprisingly, we have found similar issues within our own courses. From a recent class survey, students responded to the question, "What could the recitation leader have done differently to improve your performance on the quizzes?" Some examples of their responses were, “more examples in recitation,” “more worked-out problems,” and “more non-trivial problems gone through.” When examining our course structure to identify a potential solution, we found that each week, two to four sections of calculus material was being covered. Each homework assignment had about eight to 15 questions for students to practice the skills. Yet, in the students’ recitation sections, only two to four questions were being covered on average. It wzs reported via formative assessment surveys by many students taking calculus sections are prone to to learn Calculus from YouTube Channels such as Khan Academy, MIT Open Course, Paul's Online Math videos, etc., over learning during lectures and recitations. However, these videos are designed for a larger community of mathematics crowd, and there is no way to customize them based on the student needs.

To address this issue, the second author decided to develop and implement short and high quality instructional videos (henceforth called recitation videos) to supplement the recitation sections for students with the overarching goal of promoting student success in calculus. To make the videos even more effective for student learning, the Mathematica-generated visual aids are blended in the videos as well as the interactive simulations generated by Desmos (Desmos, 2021) and the Wolfram’s Demonstrations Projects (Wolfram Demonstration Projects, 2019). Students have shown great appreciation of these visual aids in written surveys.

Description of the Videos

To design effective videos for each section of calculus, it is crucial (i) to determine measurable and solid learning objectives for each section, (ii) determine the skills necessary to achieve each learning objective. Then, create a good number of relevant exercises from trivial to non-trivial to practice these skills. On average, five to 10 exercises are carefully picked so that each exercise tests one or multiple skills. Even though recitations are good sources of practice, the available time and the number of exercises gone through during recitations are very limited. To support the teaching, recitation and lecture notes are designed in PowerPoint, compatible for video recording. The second author also developed Wolfram (Wolfram Demonstration Projects, 2019) or Desmos (Desmos, 2021) demonstrations, 2D or 3D simple visuals blended within the videos, to make mathematical concepts (i.e. rate of change, differential, Intermediate or Mean Value theorems) more reachable by students. It is always the intension that videos have a good blend of the interaction between content, student learning. The reader may refer to Mayer (2009) to learn about more on the multimedia design for effective student learning.

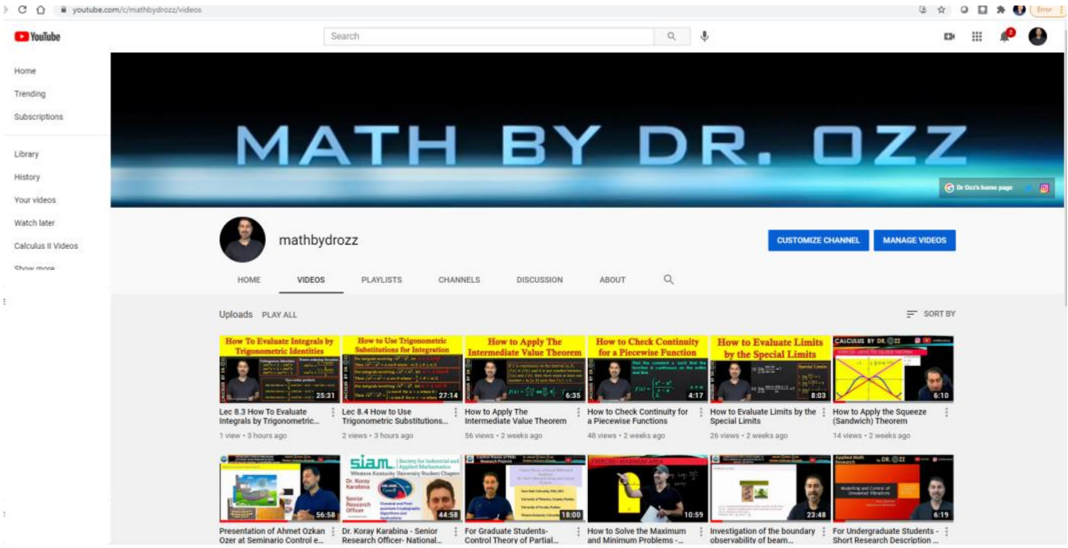

Figure 1. The YouTube channel of the second author where the videos are uploaded and shared by students with an “unlisted” fashion.

Once this stage is complete, the second author started recording the videos at two different locations, each of which require a different technology setup, knowledge, and preparation. The first recording location was at a professional studio at the author’s institution.

This professional studio is equipped with three major technologies:

- LiteTouch: A 65” touch screen computer allowing the user to annotate over anything visible on the screen. The LiteTouch has built-in software called "LitePen" which allows the user different annotation options custom made for the LiteTouch.
- Lightboard: A glass screen allowing an instructor to create unique and visually engaging videos for your course.
- Green Screen: A tool which enables content to appear behind the instructor.

To record videos, the coordinator of the studio allocates one three-hour time slot during the week, and one is left alone during shooting. For that reason, it is crucial to have all the materials, i.e. PPT and PDF files, simulations and demonstrations, ready and double-checked before you show up at the studio since the software you usually use to prepare your content may not exist in their computers. Indeed, it is difficult to edit something during shooting. Once the shooting rolls, it may take several tries to record your best shoot. Not to mention, it is expected to have lots of trial & errors. The professional studio does not provide professional editing for videos. Therefore, it is mostly on one to learn editing software to professionally edit the recorded pieces. The second author estimates that for one short instructional video, one is expected to spend at least three hours from preparation to post-production. This may gradually go down as one gets more experienced during this process.

Unfortunately, after the COVID-19 pandemic started in March 2020, access to the professional studio was shut down completely. Therefore, the second author, with the accumulated experience in recording and editing since March 2019, made an investment to convert one of the rooms in his home into a professional home studio. The home studio is equipped with all the technology used in the professional studio except the Lightboard. This is replaced by an iPad Pro which turns out to be a more advanced and more effective tool during shooting, see Figure 2. Here is a list of major hardware and software used during shooting:

- Green screen
- An iPad Pro with an Apple Pen
- A desktop (or laptop) which has a very fast processor, display card, and ample memory or storage space
- Two external cameras
- Two wireless microphones
- Umbrella lighting kit
- Three external monitors
- A video-recording software, i.e. CamStudio, VLC, IMovie, OBS
- A video-editing software, i.e. Windows Movie Maker, iMovie, Open Shot
- Multiple external storage units (at least 5TB)

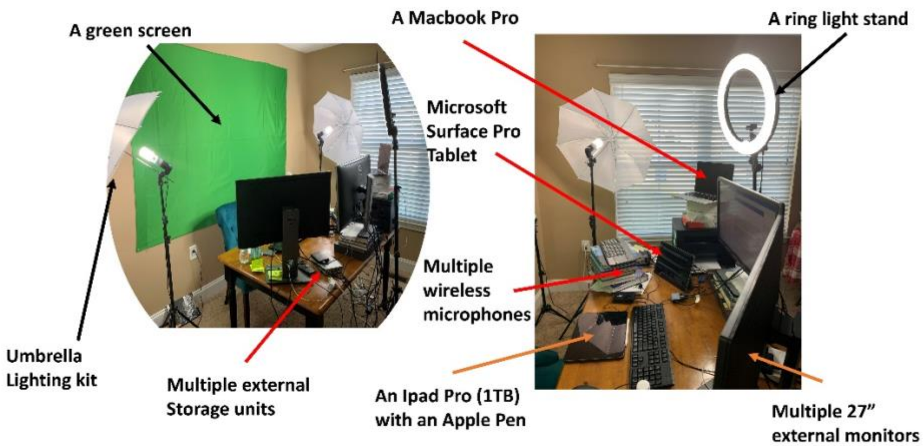

Figure 2 The professional home studio of the second author equipped with video-recording hardware.

It is crucial to note that post-editing and post-captioning is a key to design effective videos. The videos were chosen to be published on the YouTube channel of the second author with the "unlisted" format so that they are only shared to students and not public (Math by Dr. Ozz, 2021). In terms of the logistics and the number of videos to be recorded, the second author discovered (Math by Dr. Ozz, 2021) that recording at a home studio is much more effective. Overall, over 200 tutorial videos and over 100 lecture videos were recorded. Note that planning ahead plays an important role throughout this process. Refer to Table 2 in the Appendix to see the contents of sample videos.

Methodology

Our research objective was to understand how the recitation videos impacted students' calculus learning. In particular, we wanted to answer the following: 1) Do recitation videos have short-term or long-term effective in improving students' academic performances? 2) Given recitation videos are present, does it make a difference to have GTA's? In other words, are GTA's still needed, if the recitation videos are present?

To answer these questions, we recognized that learning is not simply quantified by traditional assessments. Instead, we wanted to capture the entire picture of student learning – one that captured quantitative measures on traditional assessments but also qualitative measures on students' perceptions. That is, in addition to traditional assessments, we also wanted to know about how the videos were or were not contributing to student learning. As such, we knew that only quantitative data "may not tell the complete story" (Creswell & Plano Clark, 2011), and as such, employed a mixed-methods approach.

To answer our question, we collected data on students from a semester-based calculus one course open to all majors on campus (those enrolled in the second author's sections). The collection of data started in fall 2019 for two or three different sections calculus per semester. We will continue collecting this data until spring 2022. For all the calculus sections, students come with totally different precalculus backgrounds, and during the first week of the semester, precalculus concepts are reviewed to equalize the precalculus competency among the students. Then, a calculus readiness test is given to determine the level at which students are entering the course. There are six questions measuring certain precalculus skills of the students, i.e. functions and their graphs, trigonometry, exponential and logarithmic functions, and inverse functions. Two semester tests, ten quizzes, and a final exam are also administered in addition to the surveys administered twice during the semester (once early and once later) to gauge students' perceptions and opinions on the course and videos, and interviews with select students following a semi-structure approach.

The second author administered the survey anonymously online twice a semester via Blackboard. The focus of the survey was on course delivery, teaching methods, the GTA, instructor, and specifically, the videos. We felt that this focus was important as it: could help verify whether the second author's teaching strategy worked well with his students, and more importantly, if students felt respected in his course as demonstrated by the second author's willingness to change his teaching strategy to meet the needs of his students. After the first survey was administered around the third week, the second author adapted his teaching in response to the survey. After the second survey was administered around the tenth week, the second author used these responses to verify if the changes made after the first survey were recognized by the students as useful.

To analyze the quantitative data, we utilized analysis of covariance (ANCOVA) to assess the effects of the recitation videos or TA on students' learning of calculus and a calculus readiness test to determine the level at which students were entering the calculus class regarding their knowledge. Our statistical model is:

$$Y_{ij} = \mu_{.} + \tau_i + \gamma(X_{ij} - X_{..}) + \varepsilon_{ij}$$

where Y_{ij} is the jth observation on the response variable in the ith group, X_{ij} is the jth observation on the covariate (readiness test score) in the ith group, $\mu_{.}$ is the overall mean, τ_i are the fixed treatment effect with $\sum \tau_i = 0$, γ is a regression coefficient for the relation between X and Y, and ε_{ij} are independent identically distributed normal random variables with mean zero and variance σ^2. In our study, we used student's exam 1 grades to study the short-term effect of our treatments. In this case, the response variable Y_{ij} is the exam 1 grade of the jth student in the ith treatment group. To study the long-term effect, we utilized the final exam grades as Y_{ij} instead.

To analyze our qualitative data, we first read through our survey responses and interviews to get a general understanding of potential themes developed in these data. That is, we did not interpret these data with an a priori theoretical framework. Instead, we looked for emergent themes from the student responses. Once this initial read was finished, we went back through the data to identify supporting statements of these initial themes and to determine saliency of the initial themes. These themes were presented to all three authors for verification.

Results

In this section, we will share the quantitative and qualitative results.

Quantitative Results

To study the effect of recitation videos and TA, we adopted the experimental settings shown in Table 1. There were two sections of Calculus I classes in Spring 2020: one with videos and the other without videos. There were three sections of Calculus I classes: one with TA and two without TA.

Table 1. Experimental settings of the class sections

Year	Semester	Section	TA	Video
2020	Spring	136-002	Yes	No
2020	Spring	136-005	Yes	Yes
2020	Fall	136-703	No	Yes
2020	Fall	136-704	Yes	Yes
2020	Fall	136-706	Yes	Yes

To study the effect of recitation videos on students' learning, we used the data obtained from the two sections of Calculus I classes in Spring 2020: one with videos (treatment group) and the other without videos (control group). To study the effect of TA, we use the data obtained from three sections from Fall 2020: one section with TA (treatment group) and two without TA (control group).

Table 2 and Table 3 present summary statistics of the students' learning outcomes in these two semesters, respectively.

Table 2. The mean score of each exam for both the control and treatment group for the first question.

	Control Group (No video)	Treatment Group (With video)
Size	23	18
Readiness	73.46	62.25
Exam1	65.97	70.15
Final	74.70	82.11

Table 3. The mean score of each exam for both the control and treatment group for the second question.

	Control	Treatment
Size	20	27
Readiness	86.6	86.5
Exam1	76.2	66.9
Final	91.0	82.9

Table 4 summarizes the model-fitting results using ANCOVA. For the first research question on the effect of recitation videos, the output indicates that there is no significant short-term effect, with the p-value for the treatment effect being 0.307, while there is a significant long-term effect, with the p-value for the treatment effect being 0.020. This result means that the effect of the recitation video is not significant in the short term (about one month) but is significant in the long term (about four months).

For the second research question on the effect of TA, we obtained similar results. The output indicates an insignificant short-term effect but a significant long-term effect. This means that the effect of the TA is not significant in the short term (about one month) but is significant in the long term (about four months).

Table 4. Analysis of variance results for both questions in short and long terms.

Question 1: The effect of Videos					
	Effect	Df-n	Df-d	F	P value
Short-Term	readiness	1	38	2.737	0.106
	treatment	1	38	1.027	0.307
Long-Term	readiness	1	38	4.411	0.042
	treatment	1	38	5.899	0.02
Question 2: The effect of TA					
	Effect	Df-n	Df-d	F	P value
Short-Term	readiness	1	47	15.1	0
	treatment	1	47	3.554	0.066

Long-Term	readiness	1	47	4.225	0.082
	treatment	1	47	4.124	0.048

Qualitative Results: Formative Course Assessment Surveys

In this section we will share some of the results found from the formative course assessment survey (FCAS) administered around weeks three (85% participation) and ten (80% participation). The survey is intended to measure (i) the impact on learning, (ii) the length of the videos, (iii) the format/medium of the videos, (iv) the quality/clarity of the videos.

The survey results show that 65% of the students initially agreed in the first survey that "*The instructional videos contributed to my achievement of the learning objectives for each section*", whereas this increased to 82% in the second survey, see Figure 3. Moreover, 65% of students in each survey agreed that "*Watching instructional videos aligns with my learning preferences*," see Figure 5. Around 25% of the students were neutral given that the course delivery is switched from synchronous to asynchronous teaching in March 2020 due to the COVID-19 pandemic.

Another survey question revealed that around 75% of students liked that they can pace their own learning with the instructional videos. Moreover, around 35-40% of the students watch the videos for clarification whereas 25-35% and 30% of students watch for the reinforcement of concepts and review, respectively. Only 10-15% of the students watched videos for practice and retention, see Figure 4.

Over 75% of the students indicated satisfaction with length of the videos which are intended to range from 3 minutes to 8 minutes. However, over 70% of the students still has a tendency to fast forward portions of the videos. Another related question measured that students predominantly (over 80%) watch edthe videos 1-2 times. Seventy-five percent of students took notes while watching whereas 25% watched/listened, see Figure 6.

Almost 70% of the students were satisfied with the design/format/medium of the instructional videos, and about 75% of the students were satisfied with the visual clarity of the instructional videos. Another question indicates that almost all students liked to see their instructor in the videos. Measuring the quality of the format of the videos is particularly important for this research since students tend to watch other available videos on the assessment system the e-book of the course provides (by Cengage), YouTube channels, Khan Academy, or other platforms. The majority of the students indicated that the instructional videos of the second author were of the same quality or even better than others since they are more specific to course content, see **Error! Reference source not found.**. Also, the second author
has plans to improve these videos in the near future based on the student feedback.

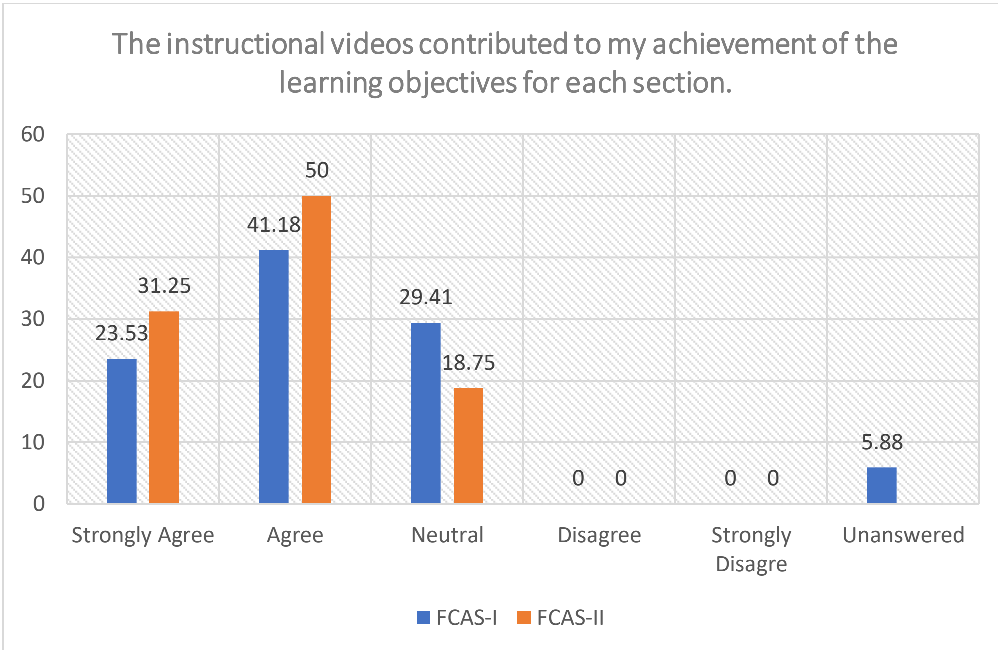

Figure 3. A question from the spring 2020 formative surveys I and II.

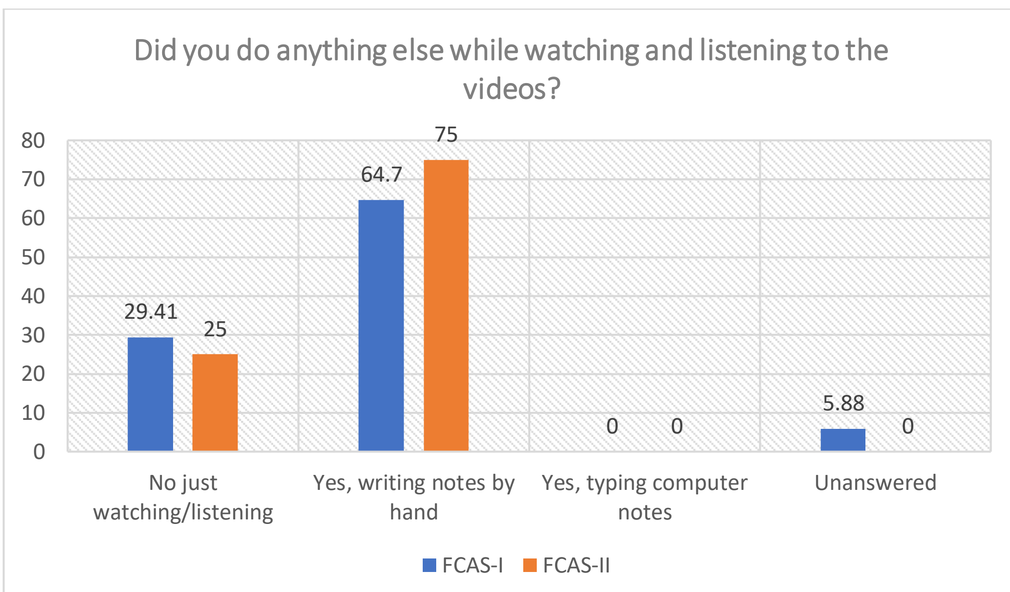

Figure 4. A question from the spring 2020 formative surveys I and II.

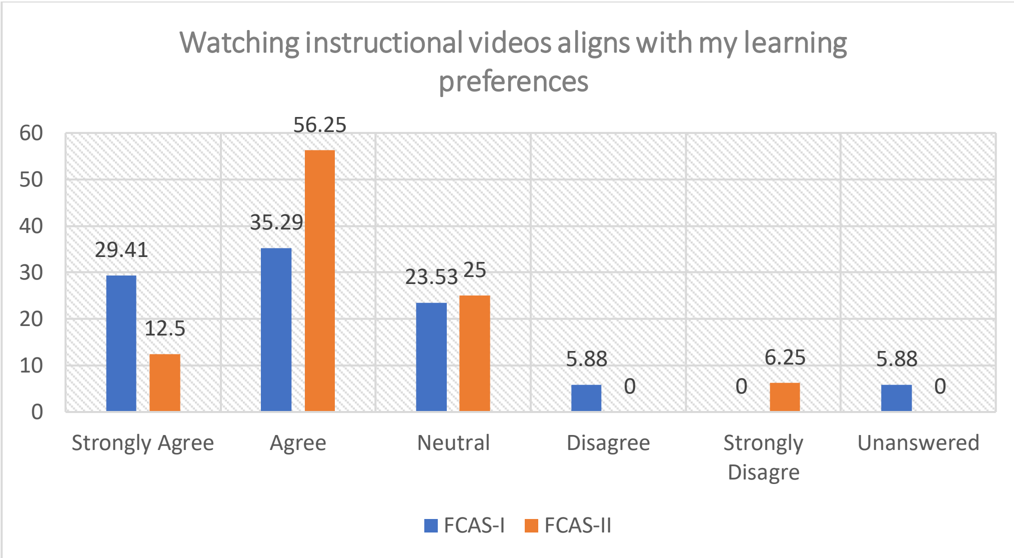

Figure 5. A question from the spring 2020 formative surveys I and II.

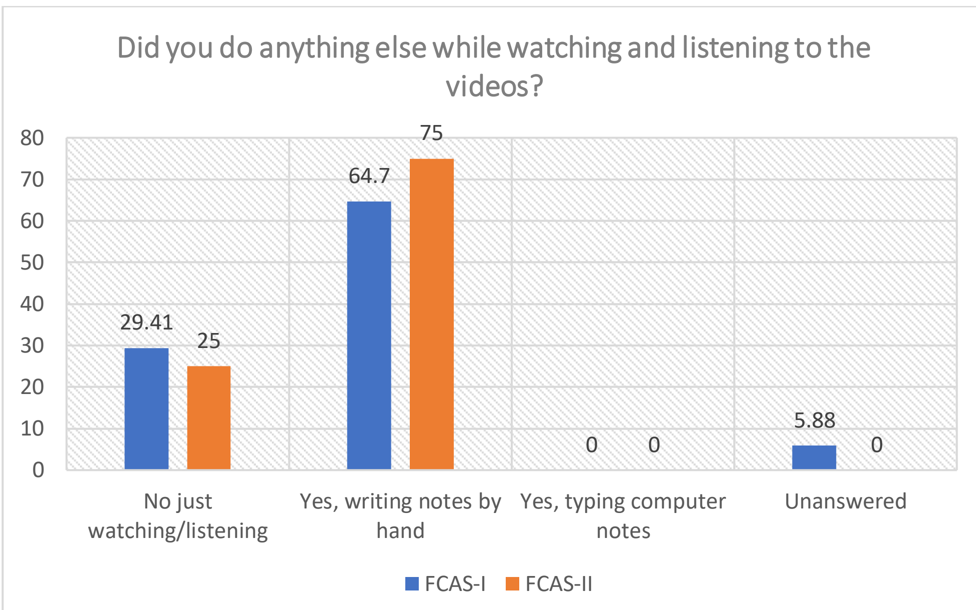

Figure 6. A question from the spring 2020 formative surveys I aand II

As part of the formative assessment survey, we asked students to compare the videos the similar videos from WebAssign, Khan Academy, Paul's Online Math Notes, and similar resources. Some sample responses for this questions can be found in Table 5.

Table 5. Sample responses on formative assessment survey asking students to compare resources.

"The videos in the e-book just pull the numbers out of thin air it seems and they dont do a good job explaining what and why they are doing what they are in the problem. P.S. There is good ambient music in the background which is nice."

“I'd much rather prefer the instructor’s videos than Webassign’s. Khans Academy can be helpful at times, but Ozz's video still top them.”
“The professor does a good job of making sure that those who want to understand the material can if they watch the videos, he is very clear and concise. In comparison to other videos online, he skips some of the small steps that should be understood, which saves time and is a big help, because he skips the redundant steps.”
“The instructor's videos are a more in-depth and much better format than those on other websites.”
“Dr. Ozz's videos are easier to understand because they are just over what we learned in class and not extra info that doesn't pertain to the problem.”

Qualitative Results: Semi-Structured Interviews

Three themes emerged from the student interviews. First, students reflected on how the videos deepened their understanding of the topics. A student stated, “I think without the videos I would be really lost.” Another noted, “[the videos] have helped me understanding [calculus] better.” Second, students often commented on the differences between watching the recitation videos and going to their recitation course. Particularly, these students noted how the live recitation was useful in that you could ask a question and get an immediate response whereas this is simply not possible given the currently technology with videos. Finally, students commented that although the videos deepened their understanding, they still wished for more variety in the problems presented. A student said, “I wish sometimes there was a bit more variety in the examples.” Another similar response was, “more variety in the types of problems being solved . . . I’d prefer them to be more complex problems.”

Mixing Our Results

As is common in mixed methods research, we will now consider the results from the quantitative and qualitative data sources collectively as this can paint the richer picture of student learning regarding the recitation videos. As we can see, quantitatively students achieved long-term positive results regarding their learning as was also evident in the surveys and interviews. This triangulation of results demonstrates a strong case for the usefulness and impact of the recitation videos. This success, given the importance of the calculus course in STEM majors coursework, is crucial to be shared with the research community. However, we also recognize opportunities for improvement as was demonstrated in both the quantitative and qualitative results. The quantitative results indicated that no short-term effect was noted. Additionally, the qualitative results indicated that students wished for a variety in the problems presented in the recitation videos. As such, an opportunity for improvement that might produce short-term positive effects could include more complex problems presented and a more immediate way to receive feedback from questions while watching the videos.

Conclusion and Future Work

In our future work, we plan to continue collecting this data regarding calculus 1 courses. In addition, we will expand data collection and analysis into calculus II, where the second author has been developing videos based on lessons learning from the study presented here. Additionally, the second author continues to revise and develop videos based on the feedback from this work, with more inclusions of Wolfram's Demonstrations Projects, Desmos, and Geogebra.

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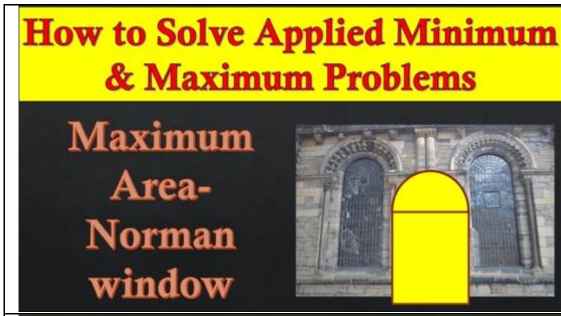
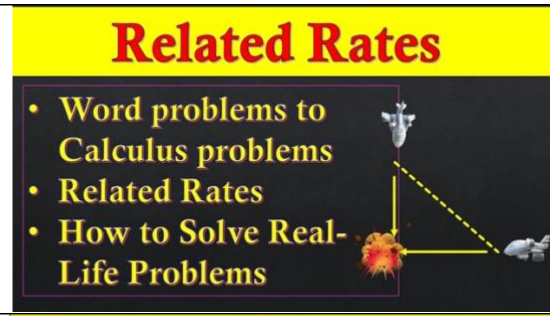
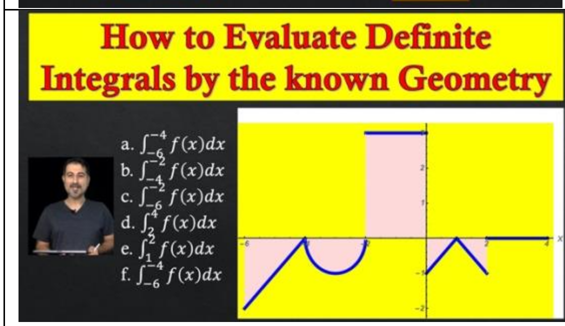
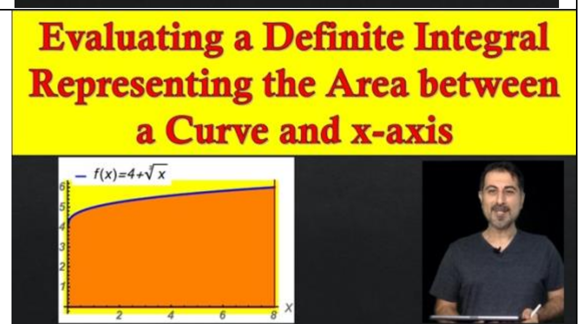
Appendix

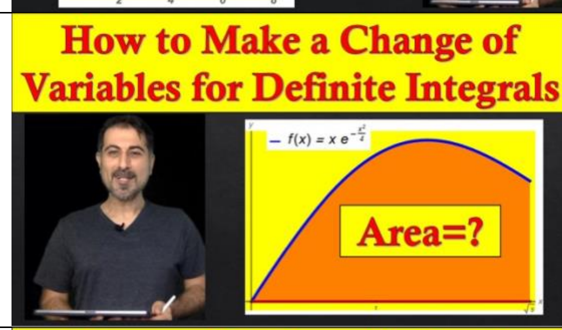
Table 1 Selected contents of videos

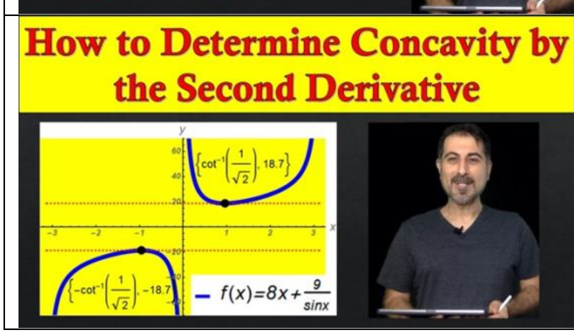


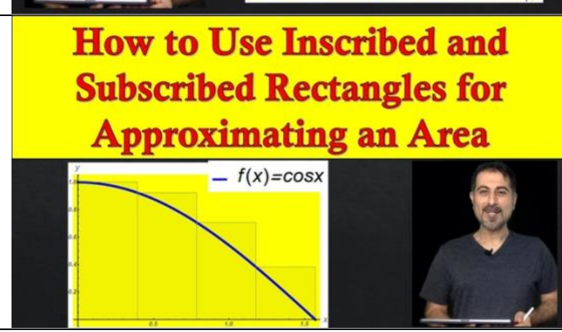


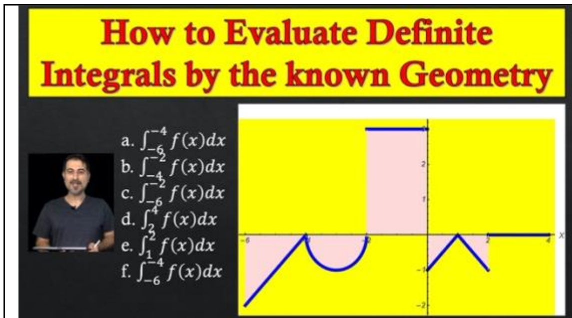


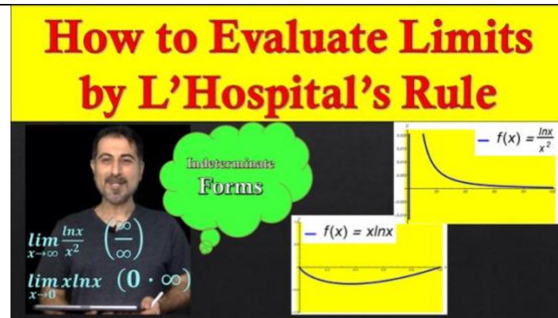


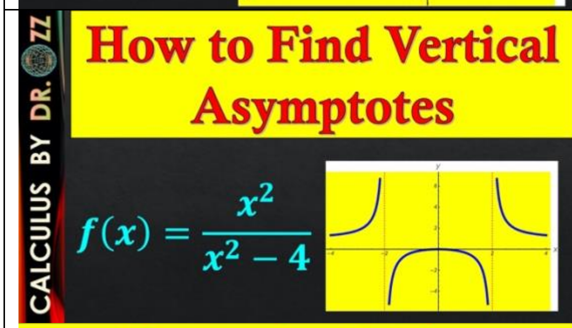


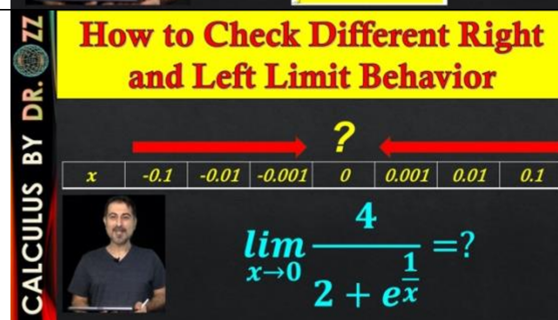


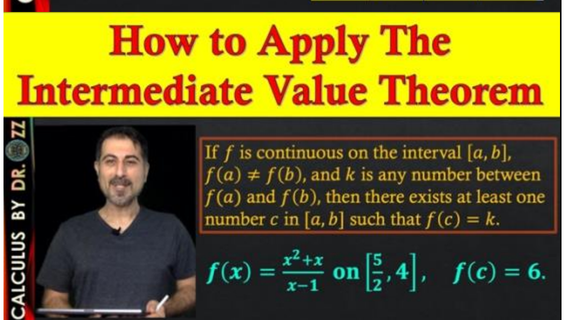


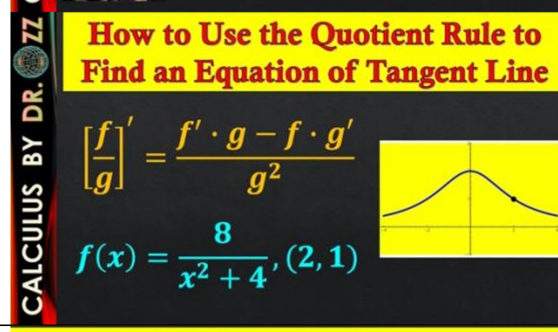

How to Evaluate Definite Integrals by the known Geometry
a. $\int_{-6}^{-4} f(x)dx$
b. $\int_{-4}^{-2} f(x)dx$
c. $\int_{-6}^{-2} f(x)dx$
d. $\int_{2}^{4} f(x)dx$
e. $\int_{1}^{2} f(x)dx$
f. $\int_{-6}^{-4} f(x)dx$

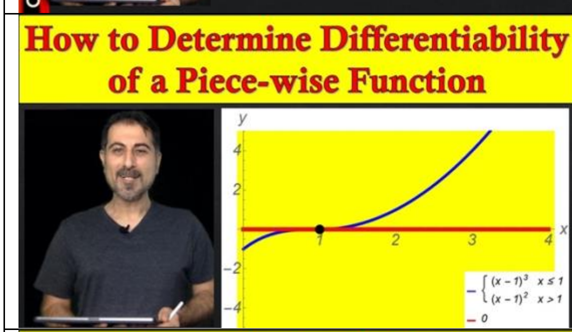

How to Evaluate Limits by L'Hospital's Rule
Indeterminate Forms
$\lim_{x\to\infty} \frac{\ln x}{x^2}$ $\left(\frac{\infty}{\infty}\right)$
$\lim_{x\to 0} x\ln x$ $(0 \cdot \infty)$
$f(x) = \frac{\ln x}{x^2}$
$f(x) = x\ln x$


CALCULUS BY DR. ZZ
How to Find Vertical Asymptotes
$f(x) = \frac{x^2}{x^2 - 4}$


CALCULUS BY DR. ZZ
How to Check Different Right and Left Limit Behavior
?
x | -0.1 | -0.01 | -0.001 | 0 | 0.001 | 0.01 | 0.1
$\lim_{x\to 0} \frac{4}{2 + e^{\frac{1}{x}}} = ?$


How to Apply The Intermediate Value Theorem
CALCULUS BY DR. ZZ
If f is continuous on the interval $[a, b]$, $f(a) \neq f(b)$, and k is any number between $f(a)$ and $f(b)$, then there exists at least one number c in $[a, b]$ such that $f(c) = k$.
$f(x) = \frac{x^2+x}{x-1}$ on $\left[\frac{5}{2}, 4\right]$, $f(c) = 6$.


CALCULUS BY DR. ZZ
How to Use the Quotient Rule to Find an Equation of Tangent Line
$\left[\frac{f}{g}\right]' = \frac{f' \cdot g - f \cdot g'}{g^2}$
$f(x) = \frac{8}{x^2 + 4}, (2, 1)$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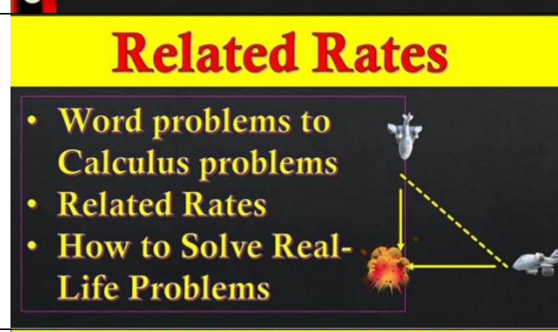
$\begin{cases} (x-1)^3 & x \leq 1 \\ (x-1)^2 & x > 1 \end{cases}$
0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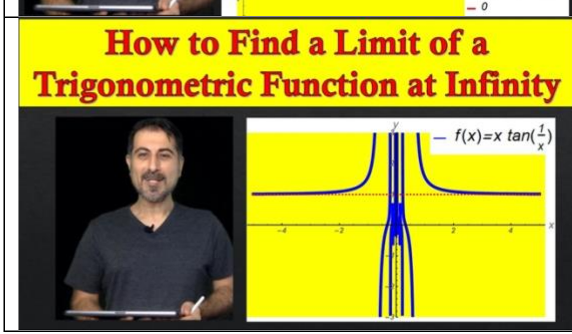
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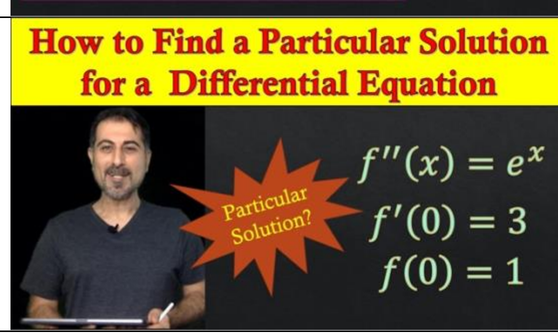
$f(x) = x\tan(\frac{1}{x})$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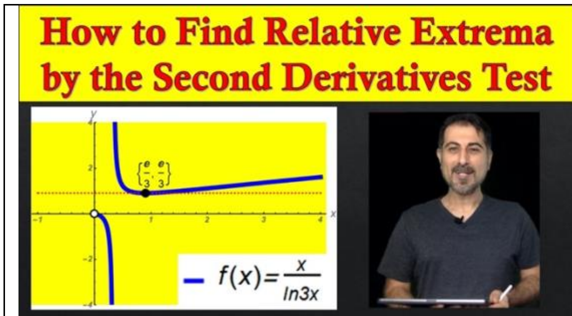
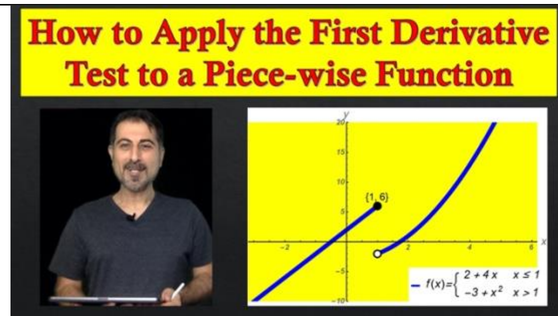
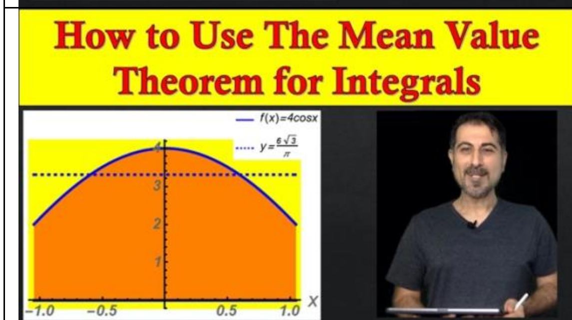
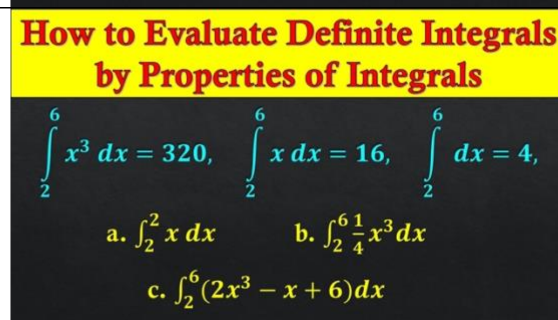
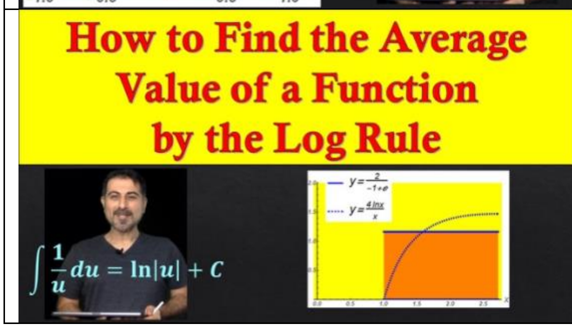
Particular Solution?
$f''(x) = e^x$
$f'(0) = 3$
$f(0) = 1$


How to Find Relative Extrema by the Second Derivatives Test
$f(x)=\frac{x}{\ln 3x}$


How to Apply the First Derivative Test to a Piece-wise Function
(1, 6)


How to Use The Mean Value Theorem for Integrals
f(x)=4cosx


How to Evaluate Definite Integrals by Properties of Integrals
$\int_2^6 x^3\,dx = 320,\quad \int_2^6 x\,dx = 16,\quad \int_2^6 dx = 4,$
a. $\int_2^2 x\,dx$
b. $\int_2^6 \frac{1}{4}x^3\,dx$
c. $\int_2^6 (2x^3 - x + 6)\,dx$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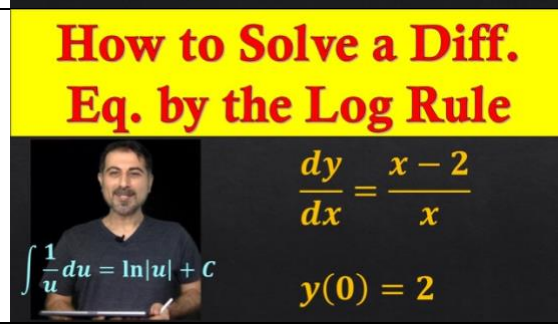
$\int \frac{1}{u}\,du = \ln|u| + C$


How to Solve a Diff. Eq. by the Log Rule
$\int \frac{1}{u}\,du = \ln|u| + C$
$\frac{dy}{dx} = \frac{x-2}{x}$
$y(0) = 2$