THE EFFECTS OF INSTRUCTORS AND STUDENT ACTIVITY IN LEARNING FROM INSTRUCTIONAL CALCULUS VIDEOS

Aaron Weinberg
Ithaca College
aweinberg@ithaca.edu

Jason Martin
University of Central Arkansas
jasonm@uca.edu

Michael Tallman
Oklahoma State University
michael.tallman@okstate.edu

We report the results of an investigation into the factors that affect students' learning from calculus instructional videos. We designed 32 sets of videos and assessed students' learning with pre- and post-video questions. We examined how students' engagement and self-identified ways of interacting with the videos connected to their learning. Our results indicate that there is a complicated relationship between the student, curriculum, instructional practices, and the video content, and that the effectiveness of instructional videos may be contextualized by both instructional practices and the extent to which the understandings supported in the videos are compatible with the meanings promoted during instruction.

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In recent years, "flipped" classrooms and massive open online courses have been promoted as effective ways to support students' active learning (e.g., Schroeder, McGiveny-Burelle, & Xue, 2015) and to deliver instruction remotely. Although there is increased interest in using these techniques and a growing body of research literature on student learning in flipped classrooms (e.g., Maxson & Szaniszlo, 2015), there is still minimal data to support claims of their efficacy.

With a few exceptions (e.g., Weinberg, Martin, Thomas, & Tallman, 2018; Weinberg & Thomas, 2018), there have been virtually no studies that have investigated how students utilize and learn from out-of-class video resources. Other research (e.g., Deslauriers, Schelew, & Wiemann, 2011) has largely been based on an implicit empiricist epistemology (Simon, 2013), assuming that exposure to out-of-class resources is sufficient to promote students' learning.

The dearth of empirical data on students' use of and learning from out-of-class resources suggests that it is imperative to investigate how mathematics students engage with and learn from instructional videos. In this report, we investigate the characteristics of students' and instructors' use of calculus video lessons that affect student learning outcomes.

Theoretical Framework and Research Questions

Both our instructional videos and research design were informed by Mayer's (2014) cognitive theory of multimedia learning. From this perspective, students are active participants in the process of learning from a multimedia presentation: they actively attend to, select, and organize information presented in the multimedia and integrate it into coherent mental representations. Thus, students' learning is influenced by the ways they engage in the video-watching process, their mental actions while they watch, and their prior knowledge and ways of thinking about the subject matter. Instructors can also play a role in the students' learning by supporting their development of particular knowledge structures and asking students to interact with the instructional media in particular ways.

Based on our theoretical perspective, we explored the following research questions:

1. Do differences between groups of students and different instructors influence how much students learn from watching instructional calculus videos?

2. How does student engagement with the videos affect their learning?
3. Do the instructors and the ways students report being asked to interact with the videos have an effect on student learning?

Methods

Materials

We created 56 instructional videos for 30 topics commonly taught in first-semester calculus. The videos were designed using Mayer's (2020) 12 principles of multimedia learning. We created pre- and post-video questions for each video set grounded in Tallman et al.'s (2021) theoretical principles of calculus assessment design. For each video set, we created a website that included a set of 2-4 multiple-choice pre-video questions, instructional videos, and post-video questions. The students were not informed whether their answers to the pre-video questions were correct but were informed of the correctness of their answers to the post-video questions and provided with unlimited opportunities to revise answers. The website collected information about when they paused or skipped while watching a video.

At the end of the semester, students were asked to complete a survey to report demographics such as gender, race, and major; indicate the mathematics classes they had previously completed; and report the ways their instructor asked them to interact with the videos (such as telling students which concepts they should learn from the video or giving credit for watching the videos). The overall response rate to this survey was approximately 32%.

Participants

In addition to one of the PI institutions (a large public university where all calculus instructors participated), fifteen instructors from fourteen institutions participated; these institutions ranged from regional liberal arts colleges to large public research institutions, located in eleven states and one international location. Data collection occurred during the fall 2019 and spring 2020 semesters; eight instructors participated during both semesters. Each instructor selected one or more video sets to assign and invited their students to participate in the study.

In addition to students who did not give consent, we excluded instances where less than 25% of an instructor's students completed a particular video set. We inferred that these responses were from students who were completing a set voluntarily rather than as part of an assignment, and might not be representative of their class as a whole. Overall, 1,166 students participated.

Data Analysis

We measured whether students' solutions on the pre-video questions were correct. For the multiple-choice post-video questions, we measured whether students' solutions were correct on their first attempt or, for the free-response questions, whether their solutions were correct by their second attempt. We used a modified version of normalized change (Marx & Cummings, 2007) to measure students' gains from pre- to post-video:

$$c = \begin{cases} \dfrac{post - pre}{100 - pre} & post > pre \\ drop & post = pre = 100 \\ 0 & post = pre \neq 100 \\ \dfrac{post - pre}{pre} & post < pre \end{cases}$$

We counted the number of times each student paused or skipped backward in each video; we called these instances "revisits." We computed the average rate of revisits for each student and

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each set of videos by dividing the total number of revisits the student made for a set of videos by the total length (in minutes) of the videos in the set.

Results

Overall Learning

Overall, the students demonstrated a mean normalized change of 7.77% (SD=59.21%). Thus, there was a considerable amount of variation in the students' learning. When we investigated learning on the separate video sets, we found that there was a significant effect of the particular video set on mean normalized change (*F*(29, 16818)=82.27, $p < 2 \times 10^{-16}$).

Student Characteristics and Learning

Student Engagement with the Videos. We first investigated whether the ways students interacted with the videos was associated with learning. We hypothesized that a "revisit"—an instance where a student either paused or skipped backward in the video—reflected the students' active engagement with the video content. Overall, only 19.9% of the student-video set pairs had a non-zero rate of revisits per minute, with a mean of 0.373 (SD=0.373). After excluding outliers, a simple linear regression to predict the normalized change based on the revisits per minute had non-zero slope (*F*(1,16086)=11.45, *p*=0.00717), but this was not practically significant, with *b*=0.031384 (*t*(16086)=3.384, *p*=0.00717). Thus, the students' engagement with the videos does not appear to predict their normalized change in a practically significant way.

Instructor Relationship with Student Learning. We investigated whether different instructors were associated with different levels of student learning. For the fall 2019 semester, a two-factor ANOVA using instructor and video set as factors within each semester showed a significant effect of instructor on normalized change (*F*(20, 8294)=2.351, *p*=0.0006) as well as a significant interaction between instructor and video set (*F*(344, 8294)=1.298, *p*=0.000225). In the spring 2020 semester, there was a significant effect of instructor on normalized change (*F*(14, 7817)=2.807, *p*=0.000337) but the interaction between instructor and video set was not statistically significant (*F*(300, 7817)=1.077, *p*=0.175556).

The Role of Curriculum. One of the participating institutions in our study included multiple sections of calculus each semester in which the content and pacing in the classes were centrally coordinated. We repeated the previous analysis at this institution and found that, in the fall 2019 semester, there was neither a significant effect of instructor on normalized change (*F*(8, 3181)=0.797, *p*=0.605) nor a significant interaction between instructor and video set (*F*(153, 3181)=1.046, *p*=0.338). Similarly, in the spring 2020 semester, there were neither a significant effect of instructor on normalized change (*F*(6, 2342)=2.094, *p*=0.051) nor a significant interaction between instructor and video set (*F*(148, 2342)=0.869, *p*=0.867). However, there was still variation between instructors. To investigate this, we transformed each instructor's mean normalized change on each video into a standardized score. Table 2 shows these scores, and demonstrates that some sets had consistently higher or lower scores across instructors, while there was considerable variation for other sets.

Table 2. Standardized scores for instructors by video set at the multiple-section institution.

	Instructor								
Video Set	A	B	C	D	E	F	G	H	I
Approximating Instantaneous Rates of Change	-0.17	-0.51	-1.03	-0.32		-0.38	-0.86	-1.02	-0.30

Product Rule	0.29	-0.41	-0.21	-0.29	-0.24	-0.41	0.44	-0.48	0.40
Quotient Rule	0.52	0.36	0.80	0.11	-0.39	0.43	0.86	-0.03	0.50

The Role of Instructor Interventions. We examined the total number of types of practices each student reported and compared the sum with their mean normalized change for each video set. We calculated a simple linear regression for the mean normalized change based on the sum of the total number of types of practices each student reported. The regression equation was not significant ($F(1, 8314)=1.535$, $p=0.2154$), with an R^2 of 0.00006431, and the result also was not practically significant, with $b=0.002708$ ($t(8314)=1.239$, $p=0.215$). However, when we repeated this analysis at the institution with multiple coordinated sections, the regression equation was moderately significant ($F(1, 1530)=5.816$, $p=0.016$) with an R^2 of 0.003136 although there was little practical significance, with $b=0.013574$ ($t(1530)=2.412$, $p=0.016$).

Discussion

The results of our study suggest that it is difficult to predict how much students learn from watching instructional videos and to discern how various ways students engage with video lessons influences their learning. In general, the students in this study demonstrated positive, yet modest learning from the videos, with a considerable amount of variation.

The fact that the students watched the videos and answered the pre- and post-video questions outside of their regular class meetings suggests that the in-class instruction should not have an effect on their learning. However, there was considerable variation from instructor to instructor and a significant interaction between the instructor and video set. These results highlight the complex relationship between how the instructor incorporates the videos into their pedagogy, the curriculum, and how effectively students use the videos to learn.

It would seem likely that the ways students interact with the videos would influence their learning. However, student engagement—measured by the rate at which they "revisited" the video—did not predict their learning.

The relative consistency of students' performance at the institution with multiple coordinated sections of calculus suggests that curriculum—and its enactment— might play a role in what students learned from the videos. Additionally, the variability of instructor effectiveness by video set suggests that the effectiveness of mathematics video lessons is possibly contextualized by the extent to which the understandings supported in the videos are compatible with the meanings promoted during instruction and developed through various types of formative assessment. We hypothesize that aligning various forms of curriculum and assessment with the content of the videos would support students' learning. However, even at this institution the students did not consistently achieve positive mean normalized change scores, and there was still variation in the relative effectiveness of the videos from instructor to instructor.

We conjecture that the key to effective learning from the instructional videos lies in the ways the instructors incorporate the videos into their pedagogy. Although we didn't see a significant relationship between the number of practices students reported their instructors using, there were significant limitations to these data. In particular, the low response rate suggests the possibility of nonresponse bias, and our data don't reveal the ways in which each instructor might have implemented the various types of practices, or how frequently or consistently—or on which video sets—the instructor implemented these practices.

Taken together, these results suggest that more research is needed to understand ways in which videos can be effectively incorporated into instruction. In particular, researchers need to create detailed descriptions of the ways instructors incorporate the videos into their classes and how their students enact these instructional practices, and investigate how this activity interacts with the content of the videos to support student learning.

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