IDENTIFYING STUDENTS' ATTENTIVE FIDELITY FOR CALCULUS INSTRUCTIONAL VIDEOS

Aaron Weinberg	Jessica Tornai	Matt Thomas
Ithaca College	Ithaca College	Ithaca College
aweinberg@ithaca.edu	jtornai@ithaca.edu	mthomas7@ithaca.edu
Jason Martin	Michael Tallman	Kimberly Newman
University of Central Arkansas	Oklahoma State University	Ithaca College
jmartin@uca.edu	michael.tallman@okstate.edu	knewman@ithaca.edu

Growing interest in "flipped" classrooms has made video lessons an increasingly prominent component of post-secondary mathematics curricula. However, relatively little is known about how students watch and learn from instructional videos. We describe and use an eye-tracking methodology to investigate attentive fidelity—the degree to which students attend to the visual imagery that is the subject of the video narration at each moment in time. Our preliminary study suggests that students' attentive fidelity varies widely, but there was no evidence that this fidelity is connected to students' ability to solve calculus problems.

Keywords: Technology, Calculus, Research Methods

Over the past few decades as educators have sought to develop online courses and incorporate active learning strategies into their classrooms, they have turned to videos as a way to deliver lectures outside of a traditional classroom setting (e.g., Lage, Platt, & Treglia, 2003; McGivney-Burelle, & Xue, 2013; White House, 2013). Flipped classrooms have been used to support problem-based learning (e.g., Tawfik & Lilly, 2015) and interactive engagement (e.g., Maciejewski, 2015), and interest in using a flipped classroom instructional format in post-secondary mathematics teaching has grown (e.g., Maxson & Szaniszlo, 2015).

Despite the enthusiasm for using video lectures, relatively little is known about how students engage in the video-watching process, what they learn from watching videos, and how their actions while watching the videos might be connected to learning. Most studies of flipped classrooms have failed to distinguish in-classroom learning from out-of-classroom learning (e.g., Anderson & Brennan, 2015; Schroeder, Micgiveny-Burelle, & Xue, 2015). Weinberg and Thomas (2018) found that students displayed a wide range of ways of interpreting mathematics video lectures and called for researchers to closely examine students' video-watching activity.

The goal of this study is to begin to investigate what students attend to as they watch video lessons. In particular, we will describe a methodology for investigating students' *attentive fidelity*—whether students attend to imagery that corresponds to what instructors would identify as showing the focus of the video at each moment in time. In addition, we will present results from a preliminary study on students' attentive fidelity and learning from calculus videos.

Theoretical Background

One way of investigating students' attentive behavior—that is, the sequence of objects and images in the world that students pay attention to—is to record their eye movements as they engage in activity. Eye-tracking has been widely used in educational research, specifically to examine the ways students interpret curricular resources and, increasingly, to study students'

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mathematical thinking (e.g., Andrá et al., 2015; Inglis & Alcock, 2012; Lee & Wu, 2018; Mock, Huber, Klein & Moeller, 2016; Ögren, Nyström & Jarodzka, 2017). Eye-tracking offers a substantial advantage over self-reporting methods, which are constrained by students' limited ability to accurately reconstruct and reliably communicate their thinking in the moment.

When people interact with visual stimuli, they make a sequence of *fixations* in which their foveal vision (i.e., the center of the field of vision) is focused on a particular point for roughly 200 to 500ms (Hyönä, 2010). These fixations are connected by *saccades*, which move the foveal vision to new locations without processing information. Fixations may indicate cognitive attention (Andrá et al., 2015), difficulty extracting information (Jacob & Karn, 2003), mental calculation (Hartmann, Mast, & Fischer, 2015), or bored staring.

The *eye-mind hypothesis* (Just & Carpenter, 1980; Rayner, 2009) proposes that there is a positive relationship between what a person looks at and what they attend to. Researchers typically assume that eye movements correspond to cognitive operations (Obersteiner & Tumpek, 2016). However, Holmqvist et al. (2011) noted that it is possible for a person to be thinking about something other than what their eyes are fixated upon. From a slightly different perspective, Abrahamson and Bakker (2016) proposed that eye movements are *part of* the individual's cognitive processes rather than reflecting separate mental processes.

Methods and Methodology

The participants in the study were students enrolled in a first-semester calculus class at either a mid-sized comprehensive college or a large state university. All students in the sections were invited to participate and 13 volunteered to participate in (up to) eight interviews (all reported student names are pseudonyms). Each interview was conducted prior to the calculus topic being discussed in class. For this report, we chose a video about Riemann sums because it involved both procedural and conceptual aspects—that is, it was designed to support students' understanding of how to construct a Riemann sum and how to interpret its computation.

In the interview session, the students were first asked to solve several problems about Riemann sums using a think-out-loud protocol; the interviewer asked follow-up questions to probe their thinking. Then, the students watched a video about Riemann sums and solved several problems that were similar to the pre-video questions.

Participants' eye-movements were recorded with a Tobii X2-60 eye tracker mounted below a 22" LCD monitor. The eye-tracker captured the on-screen coordinate of each participant's fixation at a rate of 60 Hz; we called each time at which coordinates were captured a *moment*. At the beginning of each interview, the eye tracker was calibrated with a 9-point display. The participants viewed the screen without a head restriction from approximately 2 feet away, which corresponded with roughly 0.5-degree accuracy (Tobiipro, 2019).

To identify whether students attended to areas of the screen that correspond to what instructors would identify as the primary foci of each moment of the video, we created one or more rectangular *areas of interest* (AOIs) on frames of the video. We defined two types of AOIs: A *primary AOI* was meant to capture whether or not a student was focusing on the area of the screen that was conveying new knowledge or visual aids for the narration. These included:

- Areas that contained numbers or shapes to which the narrator of the video was referring
- Areas that contained text that the narrator was reading
- Areas that contained deictic animations (e.g., arrows, boxes, or circles being drawn)
- Areas that contained other active animations that illustrated a mathematical concept

A *secondary AOI* was meant to capture areas that were directly related to—or important for understanding—the primary AOI, but were not the immediate object of the narrator's focus. For example, Figure 1 shows a frame from the video with one primary (in red) and two secondary AOIs (in yellow and blue). At this moment, the narrator reads "At 90 km dust accumulates at a rate of 6 mg per km," highlighted by the primary AOI. This speech refers to the numbers 90 and 6 and the units in the table, so these were included in Secondary AOIs because they added relevant contextual information to help understand the subject of the Primary AOI.

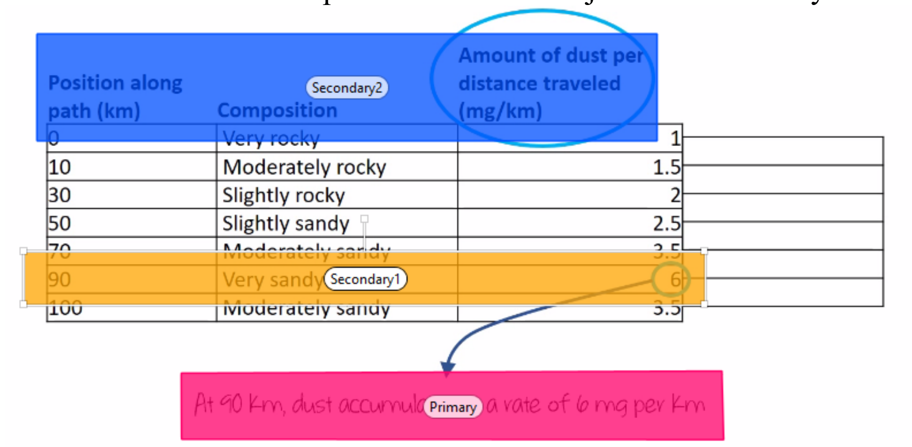

Figure 15: A Frame from the Video Showing One Primary and Two Secondary AOIs

Primary AOIs were defined for each section of the video that described mathematical concepts, but not for sections that introduced the context for the video (dust accumulating on a Mars rover). Secondary AOIs were defined whenever applicable. In order to account for the lack of perfect accuracy in the eye-tracking recording, we created each AOI with roughly a quarter inch border around the intended on-screen imagery. We measured attentive fidelity by determining whether a student's fixation was contained in one of the defined AOIs. The eye-tracker also reported information about whether it was able to locate a fixation anywhere on the screen in each moment, indicating whether or not the participant was looking at the screen.

Results

The video that the participants watched included approximately 12,500 moments in which at least one AOI was defined. Due to hardware or calibration errors, two students had a large percentage of moments (61% and 73%) in which the eye tracker was unable to detect the eye location. Concerns about accuracy led us to remove these two students' data from the study.

Table 1 shows the percent of moments for which the location of each participant's fixation was in an AOI along with whether the participant provided a correct answer to the pre- and post-video questions. The mean for the Primary AOIs was 37% (SD = 10.1%), for Secondary AOIs was 7% (SD=3.4%), and for all AOIs combined was 44% (SD=12.3%). There was substantial variation between the total percentages, with a minimum value of 22% and a maximum of 61%. There was also considerable variation in each participant's split between Primary and Secondary AOIs; for example, 45% of Camila's fixations were in Primary AOIs and only 7% were in Secondary AOIs, while Beth had much closer percentages—34% Primary and 13% Secondary.

There appears to be no relationship between whether a student had a high percentage of fixations on a Primary or Secondary AOI and their performance on the post-video questions. Of the students who got a higher percentage of post-video questions correct than pre-video questions (n=6), their total percent of fixations in an AOI was between 22% and 52% with a mean of 40%; the students whose performance decreased (n=3) had a mean of 47%.

Table 2: Summary of Results

	Percent of Moments with a Fixation on an AOI			Pre/Post-Video Question Correctness		
Participant	Primary	Secondary	Total	Pre-	Post- Q1	Post- Q2
Alec	20%	2%	22%	Incorrect	Incorrect	Correct
Beth	34%	13%	46%	Incorrect	Correct	N/A
Caleb	50%	11%	61%	Incorrect	Incorrect	Incorrect
Camila	45%	7%	52%	Incorrect	N/A	Correct
Elouise	32%	3%	36%	Incorrect	Correct	Correct
Joaquin	23%	7%	30%	Incorrect	Incorrect	Incorrect
Kayla	43%	10%	52%	Correct	Correct	Correct
Nina	44%	7%	51%	Correct	N/A	Correct
Rory	26%	4%	30%	Incorrect	Correct	Incorrect
Tristan	44%	9%	52%	Incorrect	Correct	Correct
Ursula	41%	9%	50%	Correct	Incorrect	Incorrect

Discussion

In this study we described a new methodology using eye-tracking technology for investigating attentive fidelity—whether students attend to imagery in calculus videos that corresponds to what instructors might identify as the primary foci of the videos. This involved identifying areas of interest throughout the video and measuring students' eye fixations to determine the percent of fixations that were inside these AOIs. If we accept the eye-mind hypothesis, then these percentages indicate the percent of time students were paying attention to these areas of the screen or, similarly, the degree to which this imagery played a role in the students' thinking about the concepts described in the video. Given the nature of the video—in which the Primary AOIs were constantly changing—we believe that it is unlikely that students would be thinking about the Primary AOIs if their fixations were on another part of the screen.

Our preliminary data suggest that students display a wide range of attentive fidelity and that they frequently attend to areas of the screen other than those we believe are most germane to the concepts being described in the video at any given moment. This might suggest that creators of videos need to be careful to incorporate elements that might help direct students' attention to desired areas of the screen. Conversely, it might be the case that there is no way to ensure that students will attend to particular imagery.

Our sample data do not suggest that there is a connection between attentive fidelity and change in performance from pre- to post-video questions. However, with the "coarse" nature of this measure (one pre-video question and two post-video questions) and small sample size, such an inconclusive result is not surprising.

We believe that the construct of attentive fidelity could be a useful tool for analyzing and understanding students' behavior and cognition as they watch instructional videos. Expanding the data corpus to include more videos, more students, and more detailed measures of learning would provide the foundation for generating a new, detailed perspective on student learning.

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