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Video Length Preferences for Engineering Students: Case Study of a Flipped Software Course

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ABSTRACT

Student preferences for digital learning and the COVID-19 pandemic have increased demand for asynchronous learning activities, including pre-recorded video lectures. However, there are varying recommendations and a lack of data-driven results for how long video lectures should be. This study has two purposes: 1) To determine and understand student preferences for video length in a flipped, software-intensive modeling course for engineering undergraduate students; 2) To generate data-driven evidence of actual video coverage and video length preferences. This study examined video coverage over three consecutive semesters in a software-intensive industrial engineering simulation modeling course. The first semester utilized medium-length videos (30-60 minutes) and the second semester used a mini-series of short-length (4-12 minutes) videos. In the third semester, students could choose or alternate freely between the two options. Data was collected on video coverage, student video preferences pre- and post-experiment, and learning outcomes. Students expressed preferences for the mini-series of short-length videos in a pre-assessment, but data-driven evidence and post-assessment surveys confirmed that the medium-length videos were utilized significantly more. An emergent themes analysis revealed this trend was primarily because students wanted to watch the video in one sitting. Evidence of better learning outcomes based on video length was inconclusive. Results may be limited to higher education settings where modeling and programming skills are required. More investigation is needed in other educational settings

Key words: Flipped classroom; Streaming video; Industrial engineering

INTRODUCTION

Traditional, weekly face-to-face lectures have been the standard for course delivery in higher education for decades. However, instructors have been converting to other class delivery methods such as flipped, online, and hybrid courses in part due to the flexibility this modality provides instructors and students. The transition was accelerated in response to COVID-19 pandemic-related educational policies. Student learning modality is not the same as it was a decade ago. Most of today's engineering students are from Generation Z (Gen-Z), the cohort of individuals born from 1996–2010 (Rothman 2014). Gen-Z students are 100% digitally native and are high-efficiency multitaskers (Granados 2017). They have 8-second attention spans and commonly utilize five screens (e.g., phone, computer, tablet, etc.) simultaneously. In comparison, Millennials, the cohort of individuals born from 1981-1995, have 12-second attention spans and split their focus across three screens on average (Cilliers 2017). Gen-Z students' multi-platform usage affects their focus and attention, creating challenges for engineering educators in software-intensive courses, which rely on in-class software demonstrations with follow-on lab or homework assignments. However, Gen-Z has the extraordinary ability to quickly skip information that does not interest or bring value to them due to their extensive experience as "digital natives" (Patel 2017). Consequently, traditional classroom lectures no longer provide sufficient engagement for Gen-Z students (Cilliers 2017; Olson 2014).

Since most college students today are part of Gen-Z and were born into an era of rapid technological development, technology is integrated into many facets of their lives, including education. This generation is characterized by shorter attention spans and they prefer learning by doing. Furthermore, Gen-Z gravitates towards fast delivery, instant gratification, flexibility, and opportunities for problem-solving through trial and error (Banks and Sokolowski 2010). Thus, higher education instructors must continue to advance the online learning experience to match generational demands. This work considers one facet of online instruction, video length, and provides data-based evidence of today's engineering students' preferences in a software-intensive modeling course; in this study, modeling refers to simulation modeling (Rockwell Automation 2020).

Flipped classrooms are one solution for increasing student engagement (Baker 2000). A flipped classroom reconsiders how to use "face-to-face" time effectively and efficiently (Bergmann and Sams 2014). In most cases, flipped classrooms deliver information via pre-recorded video lectures that students watch before coming to class. This approach, also known as "inverted" (Lage et al. 2000), brings active student engagement, usually in collaboration with their classmates, directly into the classroom while moving more passive activities (e.g., listening/watching lectures) outside of the classroom. These lectures provide an opportunity for students to complete their learning: 1) at their own pace, 2) at a convenient time and location for them, and 3) with the ability to pause and re-watch parts of the lecture (Koulopoulos and Keldsen 2016). Today's students are attracted to being in control of the timing, pace, and environment in which they learn (Bergmann and Sams 2012). Flipped classrooms change the traditional transfer of knowledge from a teacher-student model to a hyper-connected model where students learn from teachers and other students in the digital world, similar to how they communicate and learn about news and pop culture through social media channels (Fromm and Read 2018). Evidence shows that the flipped classroom instructional model can have a positive impact on students' learning (Albert and Beatty 2014; Demetry 2010; Strayer 2007; Wagner et al. 2013).

However, few evidence-based studies compare different video lengths for flipped classroom videos (Guo et al. 2014; Slemmons et al. 2018), and none for higher education. This paper reports findings from a study of undergraduate industrial engineering students enrolled between Spring 2019 and Spring 2020. Only one student enrolled in the study was not part of Gen-Z. The study spans three semesters and evaluates the students' preferences and performance based on video length in a flipped classroom. We use video length as the main experimental factor and evaluate student video coverage, learning outcomes, and student pre- and post-preferences for two different video lengths. Results show that the industrial engineering students in this flipped, software-intensive modeling course had higher video coverage and preferences for a single medium-length video than a mini-series of short-length videos.

THEORETICAL BACKGROUND

There are two adult learning theories that influenced the development of this research and study design: Behavioral Learning Theory (BLT) and Self-Directed Learning Theory (SDLT). BLT focuses on the idea that behaviors are learned through interaction with the environment (Kruse 2009; Rothschild and Gaidis 1981). SDLT is an adult learning theory in which individuals take the initiative to understand their learning needs, formulate their learning goals, identify resources for learning, select and implement their preferred learning strategy, and perform a self-assessment (Loeng 2020). Together, BLT and SDLT are useful for investigating video length preferences for Gen-Z engineering students.

Value of Flipped Classrooms and Asynchronous Learning

Software-intensive courses rely on in-class software demonstrations with follow-on lab or homework assignments. However, the literature shows increasing evidence of how interactive learning methods increase student engagement and perceived learning (Eijkman 2012; Greenwood 2017; Hamdan et al. 2013). The COVID-19 pandemic accelerated the surge of online learning needs and technologies for both synchronous and asynchronous learning. By embracing flipped classroom methods, instructors can provide flexibility for their students while also providing a positive and creative learning environment for complex problem-solving in engineering education (Karabulut-Ilgu et al. 2018). Flipped classrooms split concepts from Bloom's Taxonomy into different learning environments. Remembering and understanding happen while students watch videos at home, but the top four categories of applying, analyzing, evaluating, and creating remain in the classroom (Bolatli and Korucu 2020; Forehand 2010). This is important since the latter four learning objectives are the most challenging to achieve.

While studies have found that flipped classrooms positively impact student learning outcomes in engineering education (Karabulut-Ilgu et al. 2018), creating videos is not the only ingredient to the successful deployment of a flipped classroom. Instructors need to follow best practices for video development and complementary learning activities to maximize student video engagement (Guo et al. 2014; Tucker 2012). In this study, we utilize passive videos with quizzes for self-evaluation. Passive videos indicate that the students watch the videos in full before completing an assessment. The automated quizzes at the end of select videos are important to BLT. Through the video quizzes, the course instructor poses questions to the students and the students engage with the quizzes. Automated responses provide immediate feedback on 1) applications of key learning objectives communicated in the video, and 2) whether the students' understanding of those learning objectives was correct or not. Correct responses provide positive reinforcement for their learning strategy, an important component of BLT. Incorrect responses also provide valuable feedback that learning outcomes were not successfully retained or applied and that the learning strategy needs to be adjusted.

Value of Streaming Videos to Gen-Z Students

Controlling the pace, timing, and learning environment is important to Gen-Z students (Fromm and Read 2018). Gen-Z students learn primarily through the digital world, with teachers and classmates being secondary to their learning (Pearson 2018) . Consequently, asynchronous videos are appealing to Gen-Z students, and instructors have been increasingly utilizing this pedagogy for course delivery in both K-12 and higher education (Alvarez 2012; Banks and Sokolowski 2010; Bergmann and Sams 2012; Guo et al. 2014; Slemmons et al. 2018). In this study, flipped classrooms with asynchronous videos were chosen because SDLT is suitable for a software-intensive course with today's engineering students. SDLT allows students to review the videos at their own pace and use the quizzes to self-evaluate the quality and retention of their learning. This SDLT process gives control and autonomy to Gen-Z students to determine the rigor and time commitment needed to understand and apply the chapters' learning objectives. Students can seek out additional support through other resources such as a textbook, instructor, or office hours. All of these aspects of the SDLT process directly correlate with research on learning preferences of Gen-Z.

Importance of Video Length

When converting to a flipped classroom, one important question instructors should ask is "What is the ideal video length to maximize student engagement?" Many papers recommend shorter videos (Guo et al. 2014; Maher et al. 2015; Olson 2014; Slemmons et al. 2018), but few provide evidence-based results, especially after providing students with different video length options. One study that did offer two different video options discovered that middle school students have higher engagement with 10-minute videos than 20-minute videos (Slemmons et al. 2018). However, the study did not find evidence that the video length impacted short-term learning outcomes. In the setting of Massive Open Online Courses (MOOCs), a wide range of videos are offered between 5–35 minutes (Maher et al. 2015). However, a popular study reported that videos between 6-9 minutes elicit the highest student engagement (Guo et al. 2014). MOOC material is not necessarily the same as in a software-intensive course in higher education where a more direct student-teacher relationship to facilitate learning is expected. In higher education, a recent study used short videos (e.g. 5–10 minutes) to teach MATLAB programming in a flipped classroom for electrical engineers, but did not explore other video length options (Santiago and Guo 2017). Specifically, in industrial engineering, evidence suggests that 30 minutes is the optimal video length for flipped classrooms (Toto and Nguyen 2009). However, another industrial engineering study found that 25–40 minutes was 'boring' and instead converted to a mini-series of 6–12 minute videos (Olson 2014). Neither study was applied to a software-intensive modeling course. In this study, we create two different video lengths and collect both qualitative and quantitative data on student preferences.

Video Coverage

The primary response factor in this study was video coverage. We define **video coverage** as a student playing more than 60% of the module's recorded length, as tracked by the multimedia platform. Video coverage has been used to estimate student engagement, but this is debated in the literature because it does not capture the cognitive side of video engagement (Slemmons et al. 2018). More details on how video coverage is computed for each module will be given in the 'Study Design and Methodology' section. For now, note that we will use a weighted average based on video length to combine the video coverage of the short-length videos into a single video coverage metric for comparison with medium-length video coverage.

Need for This Study

Recommendations for the optimal video length are not clear, especially considering different student populations and academic settings. Given the varying recommendations for video length, we formulated two hypotheses and developed an experimental study to gather data-driven results where students were offered two video lengths. This study's design was informed by two prior studies on video length comparison for flipped classrooms (Guo et al. 2014; Slemmons et al. 2018). An important contribution of this work is the inclusion of qualitative evaluation methods (Karabulut-Ilgu et al. 2018) of student experience with asynchronous flipped classroom videos of varying lengths.

Building and explaining the development of intermediate and advanced simulation models requires 3-5 hours, which would result in many (e.g., 15–20) short videos (<10 minutes). Unfortunately, when too many components are introduced, student engagement declines rapidly (Beatty et al. 2019). There are still minimal data-driven results on best practices for software-intensive higher education courses for Gen-Z students with moderate enrollment levels (50–70 students). This study focuses on an undergraduate industrial engineering simulation course; however, the authors believe the scope of the study may extend to other software-intensive engineering courses, including computer programming, which utilize applied software demonstrations followed by student implementation and practice with various problems. Naturally, additional studies would be required to confirm extensions to other engineering disciplines and software packages.

STUDY DESIGN AND METHODOLOGY

The following section provides an overview of the research study design, the collected data, how it was collected, and how it was analyzed.

Purpose and Hypothesis

This study has two purposes: 1) To determine and understand student preferences for video length in a flipped, software-intensive modeling course for undergraduate Gen-Z industrial engineering students; 2) To generate data-driven evidence of video coverage and video length preferences.

- **Hypothesis 1:** In a flipped, software-intensive modeling course, video coverage will be higher for a mini-series of short-length videos than for a single medium-length video.
- **Hypothesis 2:** In a flipped, software-intensive modeling course, students will have higher grades on a) short-term learning outcomes and b) long-term learning outcomes after watching a mini-series of short-length videos than a single medium-length video.

Research Study Design

The study spanned three semesters (Spring 2019: 54 students, 1 section, Fall 2019: 80 students, 1 section and Spring 2020: 67 students, 2 sections). An overview of the study design is provided in Figure 1. In the first semester, students were given medium-length videos (30–60 minutes) to watch before coming to class and in the second semester, the videos were a mini-series of short-length videos

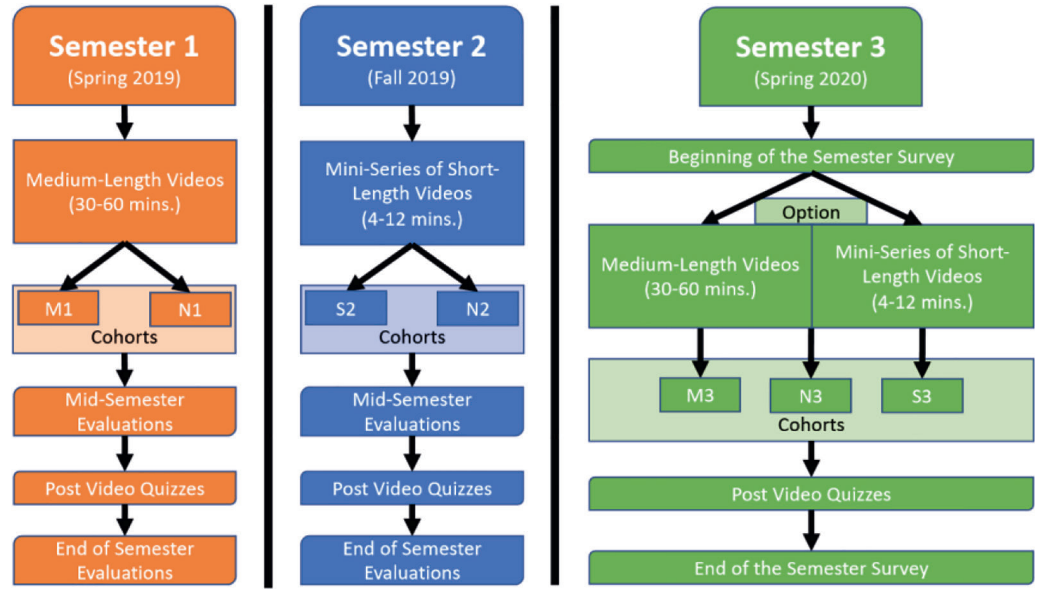

Figure 1. Overview of the research study design.

(4-12 minutes). Finally, in the third semester students were given a choice between medium-length videos and a mini-series of short-length videos. The cohorts will be defined for each module in the Results section. Students are expected to watch the videos before class to prepare for the in-class activities. In all three semesters, data was collected and analyzed at the end of each semester. The study focused on the second-half of the course when advanced simulation modeling techniques were taught using software demonstrations.

Table 1 provides the course topics and a break-down of the video lengths (in minutes) for every video in the study. Four **chapters** decomposed into a total of nine **modules**. Each medium-length video represents one module; alternatively, a mini-series of 3-5 short-length videos comprises a single module. Examples of short- and medium-length videos are available online (Basinger 2019b) and (Basinger 2019a). In the videos, the instructor demonstrates the software to model a problem, and students are expected to pause and use the software in parallel. Methodological concepts are not explicitly discussed unless they are reviewed in connection with a particular software feature (e.g., why select a certain type of resource, variable, or experimental parameter).

It is recommended that short videos have a new design, style, or objective when compared to medium-length videos (Guo et al. 2014). Thus the investigators carefully planned the videos to ensure that they did not have 'chopped' or 'broken' flow. This posed a challenge in the experimental design because the investigators wanted to maintain similar content for a fair comparison between

Table 1. Summary of video lengths and topics.

	Medium-length Videos		Short-length Videos		
Chapter	**Module**	**Length (Min)**	**Mini-Series**	**Length (Min)**	**Module Simulation Topics**
5 Modeling Detailed Operations	5.1	38:24	5.1a	11:07	Call arrivals, cut-off logic, storage
			5.1b	10:15	
			5.1c	07:40	
			5.1d	10:54	
	5.2	53:14	5.2a	06:53	Tech, sales, and order status, blocks and elements panels, shared queues and priorities
			5.2b	11:24	
			5.2c	12:10	
			5.2d	10:06	
			5.2e	12:05	
	5.3	48:24	5.3a	09:58	Arrival schedules, resource schedules, sets, resource sets, record into sets, preferred order
			5.3b	09:22	
			5.3c	06:00	
			5.3d	10:35	
			5.3e	12:24	
	5.4Q	36:42	5.4a	07:00	Tech, N-way by condition, simultaneously seizing resources, specific member, variable array
			5.4b	08:03	
			5.4c	12:09	
			5.4dQ	12:10	
6 Statistical Analysis of Output from Terminating Simulations	6.1Q	39:04	6.1a	06:37	Terminating vs. steady state, statistical issues with simulation, confidence intervals, number of replications
			6.1b	07:27	
			6.1c	04:35	
			6.1d	11:55	
			6.1eQ	08:35	
	6.2Q	38:33	6.2a	08:48	Paired T-test, output analyzer, process analyzer setup and graphs
			6.2b	11:37	
			6.2c	09:47	
			6.2dQ	06:48	
7 Modeling and Steady State Statistical Analysis	7.1	43:35	7.1a	07:16	Verification vs. validation, sequences, other modeling parameters
			7.1b	06:10	
			7.1c	06:31	
			7.1d	09:34	
			7.1e	11:50	
	7.2Q	38:30	7.2a	05:05	Warm-up period, truncated replications, interval batching logic, and output analyzer
			7.2b	11:56	
			7.2c	10:30	
			7.2dQ	10:45	
8 Entity Transfer	8.1Q	32:36	8.1a	08:59	Entity transfer using resources and transporter, animation, and conveyor
			8.1b	11:59	
			8.1cQ	11:46	

medium- vs. short-length videos. Fortunately, the medium-length videos were long enough to contain multiple learning objectives. The instructors considered the need for both video lengths and carefully crafted natural break-points between learning objectives when recording the medium-length videos. The medium-length videos were later spliced at those breakpoints to create a smooth transition to the mini-series of short-length videos. For example, a medium-length video that covered the concepts of tally statistics, resource schedules, and machine failures could be separated into a mini-series of three short-length videos on those respective topics. Instructor A created videos for Modules 5.1–5.4Q and 8.1Q, and Instructor B created videos for Modules 6.1Q–6.2Q and 7.1–7.2Q. In all data collection semesters, Instructor A or Instructor B was the primary instructor for the course.

There may be some implicit bias among students watching videos created by an instructor they are unfamiliar with. However, students were notified in advance if their primary instructor did not narrate the upcoming video. Furthermore, our analysis did not find a statistically significant difference in video coverage based on whether the primary or secondary instructor recorded video lectures.

Data and Data Collection

For this study, the team utilized Mediasite, a video capture and streaming service. To access the videos, students were required to use their unique university ID, enabling data collection of individual student video coverage. Mediasite tracks 1) how much of the video students watched (video coverage), 2) when students access/watch the videos, 3) the number of students who watch the video, and 4) the results of embedded quizzes. The team also tracked exam grades and conducted a qualitative student preference survey before and after the final semester.

Video Coverage

Video coverage was collected separately for each video via MediaSite. It is important to note that the platform only captures how long the video was played and does not necessarily represent how much the student watched or listened to the video. For each medium-length video module, we averaged the video coverage for all students who watched the video. This is further defined for Video Coverage in the Results section. For each short-length video module, we used a weighted average to combine the video coverage of the short-length videos into a single video coverage metric for the module, thus enabling a comparison to the medium-length video coverage for the module. Therefore, for each student, we took the video coverage for the individual videos in the mini-series (e.g., 5.3a–5.3e), and then used the respective video length as the weight for the weighted average computation for each student. Then, we averaged the video coverage of all students to get the average video coverage for the module. All video coverage data was collected at the time of the final exam to capture video coverage during the semester, including preparation for the final exam.

Quizzes and Exam Performance

In-video quiz scores were used to measure short-term performance, and exam grades were used to measure long-term performance. In Table 1, videos with the label ‘Q’ (e.g. 5.4Q) contained quizzes. Thus, five of the nine modules had quizzes. Each quiz had between 3–10 questions, worth 1 point each. In the mini-series of short-length videos, the quiz was placed in the last short-length video (e.g. 5.4dQ). Quizzes were not counted as a grade in Semesters 1 and 2 with the original intent of being a feedback mechanism. However, they were counted as a grade in Semester 3 to maximize participation when students were asked to complete a pre- and post-quiz before and after each module. The same questions were used in all assessments. The pre- and post-quizzes were in the same video for the medium-length modules and were separated by several videos in the short-length module series. The pre-quiz was used to establish a baseline for each student. If there is a larger increase in the pre- and post-quiz scores between groups this could indicate that the video method encourages better learning outcomes. Pre-quizzes also give students an idea of what they will be learning by exposing them to language or methods to pique their interest.

The final exam had 20 multiple-choice questions and 4 modeling problems for 100 points. Data was collected and categorized based on the lecture video it related to. Due to space constraints, we only report long-term learning outcomes for the 6.2Q and 8.1Q final exam questions.

Qualitative Survey

We performed a survey at the beginning of the third semester and Table 2 shows the pre-assessment questions and response types. The objective of the survey was to solicit the students' preferred video length to prepare for class versus the exam since previous work indicated that students utilize videos differently for each (Alvarado et al. 2020a; Alvarado et al. 2020b; Lahijanian et al. 2020). Later we completed a post-assessment to determine if the students' preferred video format changed throughout the semester. The post-assessment also asked for a brief description of the students' strategy and rationale for video length preference.

Analysis

This section explains the three statistical analyses completed on the data collected. First, we analyzed **Video Coverage** in two parts for all three semesters: 1) the percentage of students who watched the videos (medium-length vs. short-length videos) and 2) average video coverage. In the second analysis, we summarized the students' **Learning Outcomes** in two parts for all three semesters for 1) short-term and 2) long-term learning outcomes. Finally, we analyzed survey data from the third semester using an emergent themes analysis to evaluate **Student Preferences** for video lengths based on their studying habits to prepare for class vs. the exam.

Analysis: Video Coverage

To create a fair comparison between the medium-length and short-length videos for the module, a weighted average combined the video coverage from the short-length videos (e.g. Videos 6.2*a*–6.2*d*) into a single metric for comparison with the corresponding medium-length video (e.g. 6.2Q).

Table 2. Pre- and post-assessment survey questions in Semester 3.

Survey time	Question	Responses
Pre-Assessment Survey	What video format do you plan to use to get ready for class?	Single Medium-Length Videos (30-60 minutes) Series of Short-Length Videos (4-12 minutes) A combination of both formats I do not know Neither
	What video format do you plan to use to study for a test?	Single Medium-Length Videos (30-60 minutes) Series of Short-Length Videos (4-12 minutes) A combination of both formats I do not know Neither
Post-Assessment Survey	What video format do you plan to use to get ready for class?	Single Medium-Length Videos (30-60 minutes) Series of Short-Length Videos (4-12 minutes) A combination of both formats I do not know Neither
	What video format do you plan to use to study for a test?	Single Medium-Length Videos (30-60 minutes) Series of Short-Length Videos (4-12 minutes) A combination of both formats I do not know Neither
		Slide from 0% to 100% in increments of 10%
	Briefly describe your strategy and rationale for your video length preference.	Open Response
	Did your preference in video length change during the semester?	Yes No
	If yes, how did your preference in video length change?	Open Response

During the third semester, when students were given the choice of whether to watch the medium-length videos or the short-length videos, we calculated each students' video coverage for both lengths, but accepted whichever metric was largest. As seen in Figure 2, when students attempt to watch the videos, most of them watch more than 60% of the video. This trend continues among the other chapters (full analysis available upon request). Therefore, > 60% became the threshold for determining if students "watched" a module and were assigned to their respective cohorts (M1, S2, M3, S3) for each module. Students who watched < 60% were placed in the Never cohort each semester (N1, N2, N3) for each module.

Analysis: Learning Outcomes

The learning outcomes analysis evaluates if there is a correlation between video length and learning outcomes by analyzing the in-video quiz (short-term) and final exam grades (long-term) results.

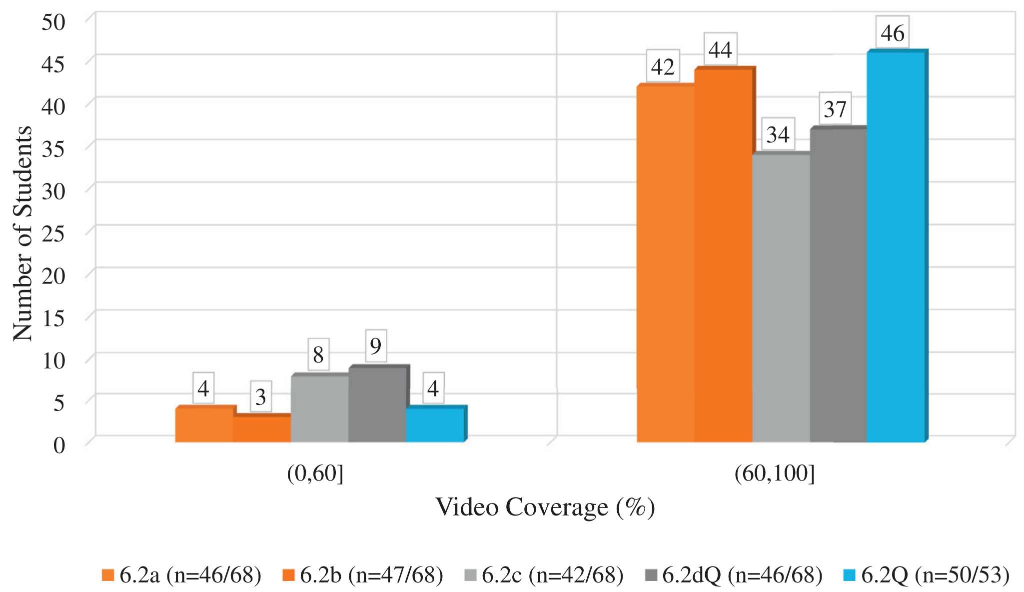

Figure 2. Video coverage histogram for Module 6.2Q.

Short-Term Learning Outcomes: For the short-term learning outcomes the same quiz questions were used for all three semesters. We ran a one-way ANOVA analysis to determine if there was a significant difference in means among the semesters.

Long-Term Learning Outcomes: For the long-term learning outcomes, we compared the students' performance on the final exam using a one-way ANOVA analysis. Final exam questions were not identical between semesters to reduce peer-to-peer content sharing between semesters. Instead, the questions were similar in structure but used different data.

RESULTS

In the reported graphs, blue represents students who watched medium-length videos (M1 and M3) and orange represents students who watched short-length videos (S2 and S3). Gray represents students who never logged in to view a specific module or with video coverage < 60% (N1, N2, and N3).

Video Coverage

Video Coverage for all three semesters is shown in Figure 3. A few trends are apparent. First, a smaller percentage of students watched the short-length videos compared to the medium-length videos. In the first two semesters, when only one video option was available to students, an average

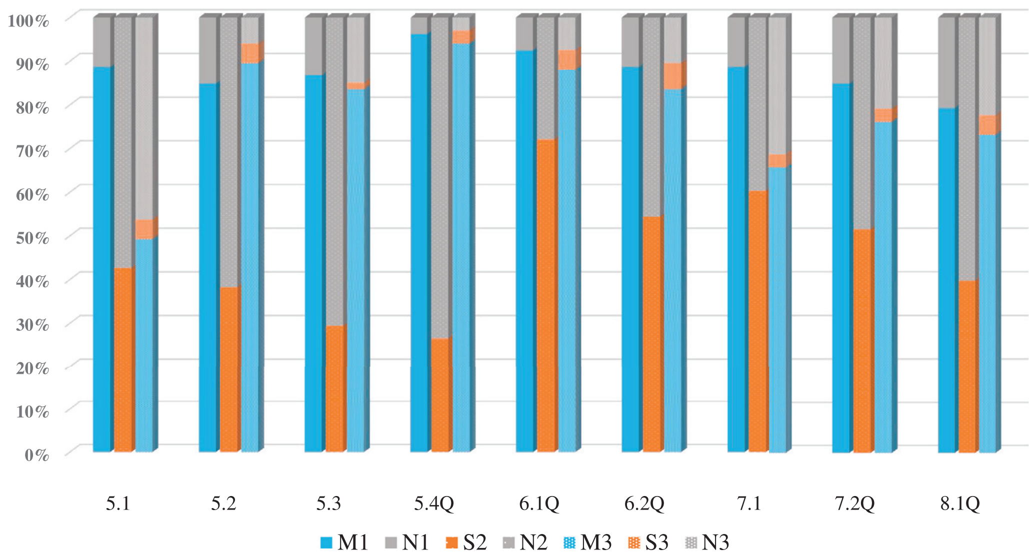

Figure 3. Percentage of students in each cohort by module.

of 88% belonged to the M1 cohorts compared to an average of 46% in the S2 cohorts. In Semester 3 where a choice was available, the results show the same trend where an average of 78% watched medium-length videos in the M3 cohorts compared to an average of 4% in the S3 cohorts.

A one-way ANOVA analysis revealed a significant difference (p-value 1.62E-07) in the size of the Never cohorts from each semester. Specifically, the averages across modules of the Never cohorts were 12.1% (N1), 54.1% (N2), and 17.8% (N3). The large N2 cohort percentage is concerning because it indicates that more than half of the class never watched more than 60% of the modules.

An average of 10% fewer M3 students watched medium-length videos compared to M1 students. This difference was more significant for short-length videos where more students watched S2 than S3. However, it is difficult to truly compare S2 and S3 due to the disparity in sample sizes and possible effects of the COVID-19 pandemic.

The second analysis for Video Coverage is shown in Figure 4, which depicts the amount of time the students watched the video and does not include the Never cohorts. A one-way ANOVA analysis among all three semesters resulted in a p-value of 6.10E-144, indicating that there is a significant difference in coverage between cohorts. When only one video option was available to students in the first two semesters, the M1 cohorts watched an average of 3% more of the videos than the S2 cohorts. Based on these analyses we reject Hypothesis 1 and conclude that medium-length videos have higher levels of video coverage for Gen-Z engineering students compared to a mini-series of short-length video in an undergraduate simulation course.

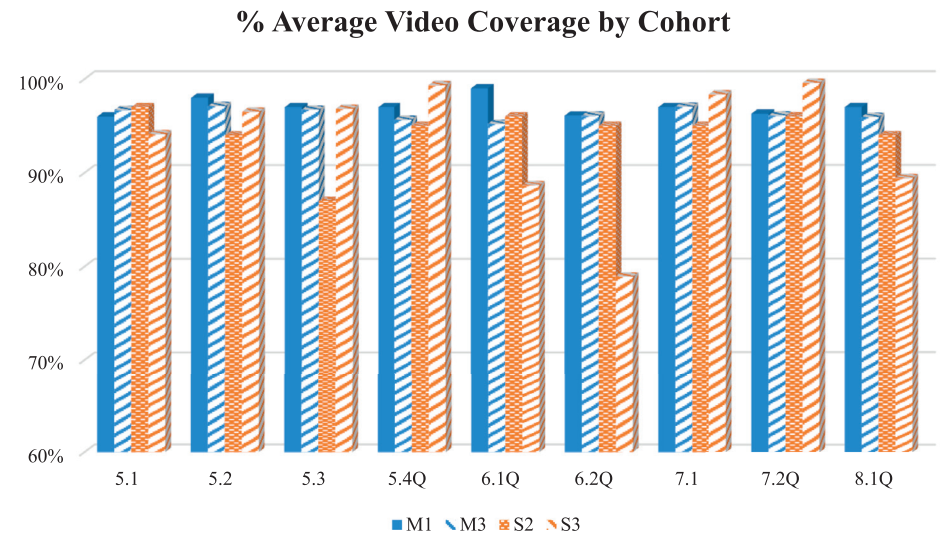

Figure 4. Percentage video coverage for each cohort and module.

Learning Outcomes

Learning Outcomes are analyzed based on 1) short-term (in-video quizzes) and 2) long-term (final exam) student performance.

Short-term Learning Outcome Results

The one-way ANOVA analysis in Table 3 shows results of in-video quizzes and the significant difference in means among the three semesters. The averages for the in-video quizzes between

Table 3. Summary of learning outcome results*

Assessment	p-value	Result	Cohorts	Outcome Assessment
Avg. of Post-Quizzes	2.10E-44	Unequal	All cohorts	
Avg. of Post-Quizzes	7.04E-10	Unequal	(M1+N1) vs (S2+N2)	Short-term
Avg. of Post-Quizzes	3.83E-06	Unequal	M1 vs S2	
Pre-vs Post-Quiz 5.4Q	4.25E-06	Unequal	M3 vs. S3	
Pre- vs Post-Quiz 6.1Q	6.17E-16	Unequal	M3 vs. S3	
Pre- vs Post-Quiz 6.2Q	2.04E-10	Unequal	M3 vs. S3	Short-term
Pre- vs Post-Quiz 7.2Q	6.14E-11	Unequal	M3 vs. S3	
Pre- vs Post-Quiz 8.1Q	2.31E-08	Unequal	M3 vs. S3	
Final Exam	0.21	Equal	All cohorts	
Exam Question 6.2	1.83E-05	Unequal	All cohorts	Long-term
Exam Question 8.1Q	9.74E-10	Unequal	All cohorts	

*Pre vs Post Quiz: Compares the increase from pre- to post-quiz score for between cohorts. All cohorts: Compares all three semesters (M1+N1) vs. (S2+N2) vs. (M3+S3+N3) semesters were 54 % (M1+N1), 45% (S2+N2), and 87% (M3 +S3 + N3) respectively. However, all quizzes were graded in Semester 3, which certainly affected student "buy in" when taking the in-video quizzes and is likely the dominating factor for the much higher quiz scores in Semester 3. Quizzes were required in Semester 3 because a pre-quiz was introduced to determine if video length affected learning outcomes, and therefore had a larger increase from pre- to post- quiz. However, since the S3 cohorts in Semester 3 were very small in size, a direct statistical comparison of M3 and S3 could not be completed for in-video quizzes.

Table 3 compares learning outcomes for different combinations of cohorts. In the first section on short-term learning outcomes, we see that post-quiz scores were different when compared across different semesters. Most notably, we see this in Semesters 1 and 2. In fact, when we include the Never cohorts, there is a difference in short-term learning outcomes between groups which continues to hold when we remove the Never cohorts as well. In the second section of Table 3, there was a statistical difference in means between the pre- and post- quiz scores for all 5 quizzes in Semester 3. All modules showed an increase in quiz scores, but 6.1Q and 8.1Q presented the most significant improvement in pre- vs. post-quiz scores. The data suggests that students do gain short-term learning outcomes when watching videos, as evidenced by increased performance on post-quizzes vs. pre-quizzes. Therefore, including a pre-quiz and requiring the post-quiz may significantly increase student performance.

Because 6.1Q and 8.1Q had the most significant improvement, we selected these two quizzes for our extended analysis of short-term learning outcomes. Table 4 shows the average score for each cohort and the percentage of students who took the video quiz for all three semesters. Because the S3 cohort was too small for a fair comparison, we first focus on Semesters 1 and 2. When comparing the average quiz score across all videos, M1 performed better than S2. For individual modules such as in 6.1Q, S2 had higher quiz scores than M1, but in 8.1Q, the opposite was true. Yet, in Semester 3, S3>M3 for both 6.1Q and 8.1Q quiz scores. One could interpret this to mean that short-length videos

Table 4. Average quiz grades by cohort.

		6.1Q		8.1Q	
Semester		Avg. Quiz Grade	(%) of Students	Avg. Quiz Grade	(%) of Students
1	M1	78	92%	78	82%
	N1	15	8%	22	18%
2	S2	95	78%	44	40%
	N2	93	22%	17	60%
3	M3	90	87%	78	73%
	S3	100	4%	89	5%
	N3	57	9%	49	22%

are potentially more effective on short-term learning outcomes, but because they had smaller video coverage, the effect on the entire class was worse. Therefore, we cannot reach a conclusive analysis about Hypothesis 2 for short-term learning outcomes. More data is needed for further analysis on the effects of video length on short-term learning outcomes.

Long-term Learning Outcome Results

Long-term **Learning Outcomes** were analyzed by a one-way ANOVA analysis of overall final exam scores and two chapter-specific questions. The results are shown in Table 3. There is no statistical difference between the cohorts based on video length when comparing overall final exam scores.

However, there is a statistical difference between cohorts when we look at individual questions directly related to modules in the test group. In order of best performance by semester, we had 3, 1, 2 for 6.1Q and 1, 3, 2 for 8Q. For both questions, the semesters when students had access to medium-length videos (Semesters 1 and 3), students performed better than in the semester with only the mini-series of short-length videos. Based on these results, Hypothesis 2 is inconclusive regarding whether video length affects long-term learning outcomes.

Survey Results

The pre-assessment survey from Semester 3 was answered by 40 of 67 students, which is a response rate of 59.70%. The post-assessment survey was sent to students at the end of the semester and received responses from 41 out of 67 students, or a 61% response rate. Results are summarized in Figure 5. However, it should be noted that the modest response rates could leave the results vulnerable to selection bias as there may be a relationship between the choice of video length and the likelihood of completing the survey.

Based on the pre-assessment survey, 58% of survey respondents planned to use medium-length videos, while 23% of the survey respondents planned to use the mini-series of short-length videos.

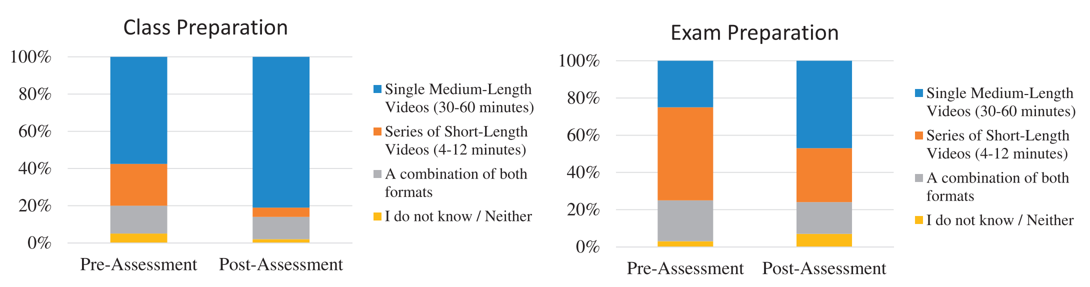

Figure 5. How students prepared (pre-) and actually prepared (post-) for Classes and Exams.

Therefore, the rest of the survey respondents (20%) did not have a strong opinion ("A combination of formats" or "I do not know") on video preference. This was an unexpected result given that the literature suggests the use of short-length videos over medium-length videos (Guo et al. 2014; Maher et al. 2015; Olson 2014; Slemmons et al. 2018). This trend is made even more evident on the post-assessment survey, where 81% of survey respondents used the medium-length videos, while only 5% of the survey respondents used the series of short-length videos. These results confirm the video coverage data collected throughout the semester. In fact, the results showed a strong preference for medium-length videos when preparing for class.

When asked how students plan to use the videos to prepare for an exam, the pre-assessment survey found 25% of the survey respondents planned to use the single medium-length videos while 50% of the survey respondents planned to use the mini-series of short-length videos to study for the exam, as shown in Figure 5. This aligned with our expectation that students would use the mini-series of short-length videos to study for a specific topic before the exam. However, based on the post-assessment survey, 47% of the survey respondents used single medium-length videos, while only 29% of the survey respondents used the series of short-length videos. The quantitative data on video coverage confirmed the students' self-assessment because they more heavily utilized medium-length videos when preparing for the exam.

The assessment yielded an interesting relationship between what students perceived to be their preferred video format and what video format they actually used. Table 5 reports the conditional video preference changes. None of the eight (8) students who planned to use the series of short-length videos to prepare for class stayed with their original choice, whereas 20 of 21 students who planned to use the medium-length videos actually did. Students that initially did not have a strong video length preference also leaned toward using medium-length videos.

Table 5. Number of students who changed video length preferences for class and exam preparation.

Planned	Changed to	Class	Exam
Short-Length Videos (8 Class, 17 Exam)	Medium-Length Videos	7	5
	Short-Length Videos	0	6
	A combination of both formats	0	4
	Neither	1	2
Medium-Length Videos (21 Class, 9 Exam)	Medium-Length Videos	20	9
	Short-Length Videos	0	0
	A combination of both formats	1	0
	Neither	0	0
A combination of both formats or Neither (7 Class, 10 Exam)	Medium-Length Videos	4	3
	Short-Length Videos	1	3
	A combination of both formats	2	3
	Neither	0	1

Table 6. Emergent themes from qualitative survey results (31 responses).

Frequency	Motivation for preferring medium-length videos to prepare for class
11	Preferred to watch a single medium-length video in one sitting
4	Medium-length videos did not feel long and had good flow
3	Less convenient or multiple clicks required to open a series of short-length videos
2	Used the allotted class time as scheduled
2	The video platform saves your spot and created their own break-points
1	Unsure of quizzes in short-length videos and did not investigate

Similar results were observed for exam preparation. However, the preference between one format or another was not as dominant as previously mentioned. Students who were undecided or intended to use the short-length videos had varying patterns of preference changes. However, once again all nine (9) students who planned to use the medium-length videos stayed with their selection.

Table 6 summarizes the results from an emergent themes analysis on the rationale for why students preferred medium-length videos to prepare for class. Emergent themes analysis has previously been used in the literature to identify commonly occurring statements, or themes, used by participants in a written for verbal statement (Giang et al. 2021). There were 31 students who fit these criteria, but not all students provided comments or explained their video length preferences. The survey comments were reviewed for emerging themes, and ultimately six categories were identified by the research team. Certainly, the most common motivation for choosing medium-length videos was that students prefer to watch a video in one sitting. A few students reported that the medium-length videos did not feel very long and had good flow, whereas short-length videos had too many clicks. We also identified two students who reported breaking the medium-length videos into their own short-series because the video platform saved their spot upon return. There were 13/31 students (41.9%) who mentioned using the short-length videos to review for the exam because they could focus on one topic, but still preferred the medium-length videos for initial viewing. In the future, the instructors can alternatively provide a time-stamped outline for the medium-length videos.

A similar emergent themes analysis was completed for exam preparation. We identified fifteen students who used short-length videos to review specific topics for the exam. However, two students preferred to continue watching the medium-length videos because they wanted a full review of the material. Two more students did not use any videos because they felt they had taken good notes the first time or preferred to review the accompanying lecture slides.

Study Limitations

The are several study limitations worth noting. First, the course required software-intensive modeling sessions with a lot of technical detail. The study provided evidence that it is best to demonstrate these concepts in medium-length videos instead of a mini-series of short-length videos. The population of undergraduate industrial engineering students may also impact the results as they may not be transferable to K-12, other colleges (e.g., arts and sciences), or generalized to all of Gen-Z. Although each semester had a different set of instructors, the same videos were used. When designing the videos, the medium-length videos were first created and then split into the mini-series of short-length videos; the students' preference for medium-length videos could have been intuited as that was their original design.

Additionally, the quiz questions used to assess short-term learning outcomes were consistent, but the requirement for grading was not. Furthermore, it is nearly impossible to tell if students were sharing answers to the quizzes, enabling students in the Never cohorts to do well without actually watching the video. In contrast, the final exam questions were slightly altered each semester, but were designed to evaluate similar concepts and were a high-stakes component of the course's final grade. Finally, this implementation of the flipped classroom was intended to serve as "lecture replacement", meaning that the concepts were only briefly reviewed in class before being integrated into hands-on modeling activities using software in the classroom. Thus, the results may not apply to courses where instructors only want to introduce concepts through 'at-home' videos and then elaborate with an extended lecture in the classroom.

Effects of the COVID-19 Pandemic

The COVID-19 pandemic affected the course in Semester 3, beginning with video 5.4Q. Because of the established flipped classroom format, the transition to online learning was relatively seamless. Students continued watching the videos as scheduled, but the extra office hours during lecture time transitioned to Zoom. One positive note was that students attended the office hours in far greater numbers than physically coming to the classroom prior to the pandemic. The course instructor found that sharing screens via Zoom to debug simulation models was easier, and that the multiple on-lookers found value in watching the debugging process. We chose to include the data from Semester 3 because the venue/format for watching the videos did not change. Students continued to have access to the simulation software through the cloud or on their own devices.

The most notable effect of COVID-19 in Semester 3 was that students could potentially have lacked focus, resources, or motivation for completing the course, especially after the university announced that a Pass/Fail option was available. The option was announced just before the final video, 8.1Q, was released. Students in Semester 3 could elect into the Pass/Fail option after taking the Final Exam, but before Final Exam grades were available. All students finished the course, but 29 students (43%) opted for Pass/Fail grading. Numerically, the students who elected Pass/Fail had a final average that was 4.3% points lower than those who accepted the traditional grading system.

This could have contributed to the inconclusive results of the long-term learning outcomes. It was not possible to discern the underlying reason that students elected Pass/Fail, though it was notable that nearly half (n=14/29) of those electing Pass/Fail would have earned an A or A- in the course had they stayed with the traditional grading system.

CONCLUSIONS

Industrial engineering students enrolled in a software-intensive modeling course have greater asynchronous video coverage for a single medium-length video (30–60 min.) compared to a mini-series of short-length videos (4–12 min.). These results contrast with recommended practices in other settings (Guo et al. 2014; Maher et al. 2015; Olson 2014; Slemmons et al. 2018). However, the data from three semesters of an undergraduate industrial engineering simulation course provides data-driven evidence that this phenomenon is not an individual preference.

Video Coverage results showed that when students are presented with a mini-series of short-length videos, fewer students watch the videos than if they were presented in a single medium-length video. Additionally, the video coverage was greater for medium-length videos, and students still preferred the medium-length videos when given both options.

Learning Outcomes of Gen-Z students were measured in the short-term (in-video quizzes) and long-term (final exam). Including a pre-quiz may increase short-term learning outcomes, since students have an idea of what to focus on in the videos. However, the data showed conflicting results for short-term learning outcomes. The mini-series of short-length videos resulted in better quiz scores among students who actually watched the videos, but medium-length videos had better quiz averages for the entire class. Consequently, further analysis is needed to make more substantial claims regarding the impact of video length on short-term learning outcomes. For long-term learning outcomes there was no significant effect on the overall final exam grades. However, the semesters where medium-length videos were available consistently performed better than the semester with access to only the mini-series of short-length videos.

Finally, **Student Preference** was assessed through two surveys in Semester 3. Most students expected to use the mini-series of short-length videos but ultimately utilized and preferred the single medium-length videos, especially for classroom preparation. In conclusion, for instructors who are developing videos to serve as instruction "at home," for software-intensive modeling courses in higher education, the videos should be presented as a single video per topic at a similar length to the traditional lecture.

In future research, the team plans to reproduce the study in a general engineering course for computer programming (e.g. Matlab, C++). This extension would provide many similarities (e.g.

engineering, Gen-Z students, software-intensive), but would differ in other aspects (e.g. different software, different engineering discipline). In an extended study, we would also like to expand the qualitative surveys to collect information on the students' preferred playback speed so that we can better understand how this impacts the total time spent on a video. Secondly, an investigation into the video content would also be warranted. The videos used in this study primarily employed **passive learning** because students only watched the videos and occasionally took a post-quiz assessment. In **active learning** videos, students would interact with the videos by answering questions that could dynamically jump their location in the video based on their interaction. Playposit (PlayPosit 2020) offers this type of jump feature. Thus students could extend their viewing experience by requesting a more detailed explanation while more advanced learners could skip content by answering knowledge-check questions correctly.

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