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Evaluating a Flipped Lab Approach in a First-Year Engineering Design Course

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Abstract
This complete research paper will investigate the continuation of a flipped classroom initiative to develop a series of instructional videos for laboratory and design project skills at New York University. Previously, a video was created to assist with prototyping and wiring a breadboard for a lab experiment. The next video in the series is part one of a two part sequence on the engineering design process. Over the last three semesters 3D printing and computer-aided design (CAD) have been integrated into the course design project. Part one of the video uses the first half of the engineering design process to 3D model a potential print to help with the course project. The second half of the video will document printing the part and completing the rest of the engineering design process cycle.

The investigators wish to study the effectiveness of the video and use this analysis to plan the next steps for continuing the video instruction initiative. The goal for these videos is to provide all students with a fundamental background to get started on their projects and laboratory exercises. Students are required to watch the videos throughout the semester and this is enforced through a quiz administered at the beginning of the lab session each week – currently, there are only two lab quizzes based on videos, but all labs have a quiz. With the background provided by the video, the researchers aim to increase the creativity in student solutions and encourage their implementation of a systematic engineering design process.

Introduction

This paper addresses the use of the flipped classroom pedagogy and an investigation of the instructional videos in a 3 credit hour lab course, Introduction to Engineering and Design at New York University Tandon School of Engineering. The main objectives in using the flipped lab approach in the first year course were to 1) provide pre-laboratory information for hands-on lab activities, 2) assist students with the visualization of conceptual, text-based course content, 3) help the students formulate questions for problem solving in the lab or course, and 4) reinforce content retention and learning after the completion of the lab. These goals lead to the initiative to develop a series of instructional videos for laboratory and design project skills. The first video, *"Introduction to the NI Elvis Board,"* was produced to assist students with prototyping and wiring a breadboard for a lab experiment. The second video, *"3D Modeling and Design"* is part one of a two-part video on the engineering design process.

The video resources provide students with uniformity and expert guidance through a visual representation of the topics. The videos can help students learn the concepts associated with the laboratory assignment, apply them proficiently, and acquire the ability to discuss the topic with peers and teaching assistants within the lab sessions.

With this video tool there is an opportunity to present students with a resource that is visual and creative instead of the text-based lab manual that is traditionally given to students for lab preparation. Videos allow for information to be represented as a combination of words, texts, pictures, and diagrams. This type of concept representation complements different learning styles and focuses on the visual mode of teaching in the engineering disciplines (Bringardner, 2016).

The first video created for this initiative introduced breadboarding and circuit building fundamentals. Once of the course laboratory exercises requires students to use fundamental digital logic to solve a problem, translate the equations to a digital interface - LabVIEW, and build a circuit using the National Instruments educational breadboard. It was common for students to struggle with breadboard wiring when trying to translate instructions from the lab manual text to the hands-on experience. This encouraged professors and teaching assistants to seek another way to convey the information necessary to complete the lab.

Findings from investigating the use of the first video revealed several key points to consider when making new videos for the flipped lab (Bringardner, 2016). Instructors found that the optimal time for the videos was around five minutes. Students requested subtitles to make the technical terminology easier to understand and allow for viewing in public, or multiple viewings in lab without students getting tired of the audio. It was also determined that the best use of the videos was visualization of hands-on portions of the lab - with a focus on difficult to use equipment and software.

The analysis of the first lab video provided insight for the instructional team to create a video based on the course project, which also takes place in a lab setting. So, for the next video, the instructional team focused on software and equipment with respect to design concepts. A plan for creating a two part video emphasizing the engineering design process was developed. The goal of the content of these videos was to 1) train students on 3D modeling and 3D printing principles, 2) convey the engineering design process steps, and 3) inspire creativity in team design project solutions.

Students in the introduction to engineering course are required to build an autonomous robot that completes an obstacle course of their choice. Recently, students have been given the opportunity to use a 3D printed robot part or terrain modification to overcome obstacles through drafting a 3D model rather than coding their robot. 3D printing is a good hands on counterpart to computer-aided design and has become a critical component of many first-year engineering courses (Freeman, 2016). This video intends to stimulate ideas for students to take this alternative, creative problem-solving approach.

Literature Review

This study has a unique approach to using instructional videos. Most flipped classroom initiatives focus on translating in-class lectures to videos that cover the same topics. This study instead investigates the use of videos for lab equipment and software instruction. Many instructional videos rely on one of six production styles or settings: slides, real-time coding, freehand drawing on a digital tablet, classroom, studio, or office desk (Guo, 2014). The videos created for this course are instead set in the labs where students will work on experiments and projects. First-year and computer-aided design courses have used videos for a variety of topics including: technical writing, software, programming, drawing, modeling, communication, problem solving, and teamwork (Fraley, 2015; Shah, 2013; Shreve, 2011). However, the videos used in these courses prepare students to complete assignments and take exams. On the contrary, the NI ELVIS and CAD video viewed before the lab prepare students to complete hands-on exercises in the lab and for their project. This makes the visual learning aspect of the videos one of the most important characteristics of the flipped lab.

Other projects have taken a similar approach in the design and planning of videos. It is recommended that extensive preparation take place before any recording begins. Shah et al. (2013) found that the best process for creating a new video is to brainstorm, outline, draft, complete a technical review, and then record. This was the same approach the instructional team took. Abulencia et al. (2016) had their students create a series of videos. While the instructional team wanted to maintain control over the creation of the video content, teaching assistants - acting as student peers - were used to make the instruction more relevant to the students. Other studies found that videos were most effective in creating consistency in the course content (Grossenbacher, 2011), which is critical to the introduction to engineering course because it has 21 different lab sessions. Bishop and Verleger (2013) found in their extensive literature review of flipped classrooms that it is important to monitor student performance throughout the semester. This research will investigate student performance related to the video content.

Several studies on flipped classroom videos have compiled a list of best practices. Table 1 lists the top summaries of best practices from three of the most relevant studies. Most researchers identify short videos as essential, while 5 minutes is the most commonly recommended length. There is a common theme of relying on team production as well as extensive planning before the recording of the video. Ultimately, the video product will last indefinitely or until there is a change in the curriculum. Therefore, the extra time spent on planning the video is worthwhile. The other most critical element to successful videos is that they have a narrow focus. Conveying content in a video is more effective if the information is direct and avoids over complication.

Table 1: Summary of Best Practices for Flipped Classroom Video Production

Researchers	**Bruhl, Klosky, & Bristow (2008)**	**Pohl & Walters (2015)**	**Johanes & Lagerstrom (2016)**
Best Practice 1	Use short videos	Short videos (<6 min)	5-15 minutes
Best Practice 2	Focused topic	Narrow topic	Multimedia research
Best Practice 3	Common problems	Informal setting	Interactive activities
Best Practice 4	Example problems	Sketch on slides	Plan pedagogy
Best Practice 5	Down to earth	Convey enthusiasm	Team production
Best Practice 6	Avoid excessive work	Include people	Not just videos

Each of the studies in Table 1 found instructional videos to be an effective method for improving learning. Others have identified the need for instructional videos because engineering students are tech savvy visual learners, the technology is ubiquitous, and it supports repeatability and consistency (Diong, 2013). Research into classes that tested different sections using and not using video found that as students spent more time watching videos, performance on homework, exams, and final grades improved (Fraley, 2015).

Method

The videos were developed with a center for faculty support that is committed to the series of videos being created for the first-year introduction to engineering course. This center provides instructional technique advising; equipment and personnel for filming; experts in video design, development, and editing; and online tools for distribution. The second video in the series intended to make 3D modeling and CAD as engaging as possible for first-year students. The video editor was able to generate 3D hologram representations of the design to promote visualization of potential solutions – similar to those seen in popular futuristic and superhero movies. A sample of these visualizations can be seen in Figure 1. The excitement created by the video was intended to inspire students to do more in the course as well as outside the course in the university's new makerspace.

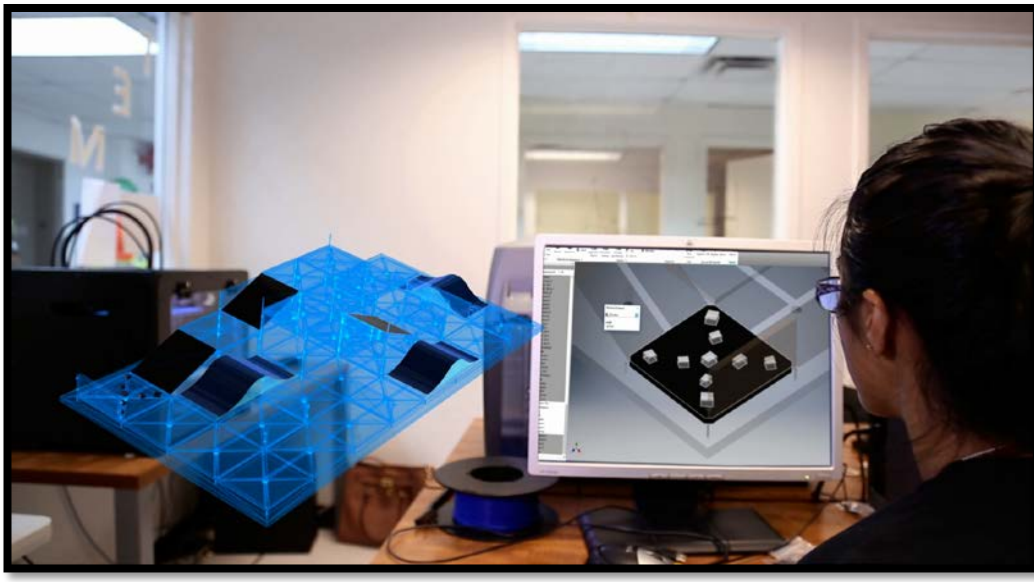

Figure 1: Screenshot of Video Demonstrating a 3D Hologram Related to the Course Project

The video uses an undergraduate teaching assistant, seen in Figure 1, performing the role of a student in the course. She examines a robot obstacle course that her team has to design and program an autonomous robot to traverse. Figure 2 is an example terrain for the obstacle course. The actress *identifies the needs* of the robot to cross obstacles and the *constraints she has to consider*. She then begins to *research the problems* that the robot might encounter. After the constraints and key issues are identified for the problem, the student in the video *brainstorms potential solutions*. At the end of the video she *identifies a promising solution* and designs the part in CAD software. A diagram of *the engineering design process* highlights these steps.

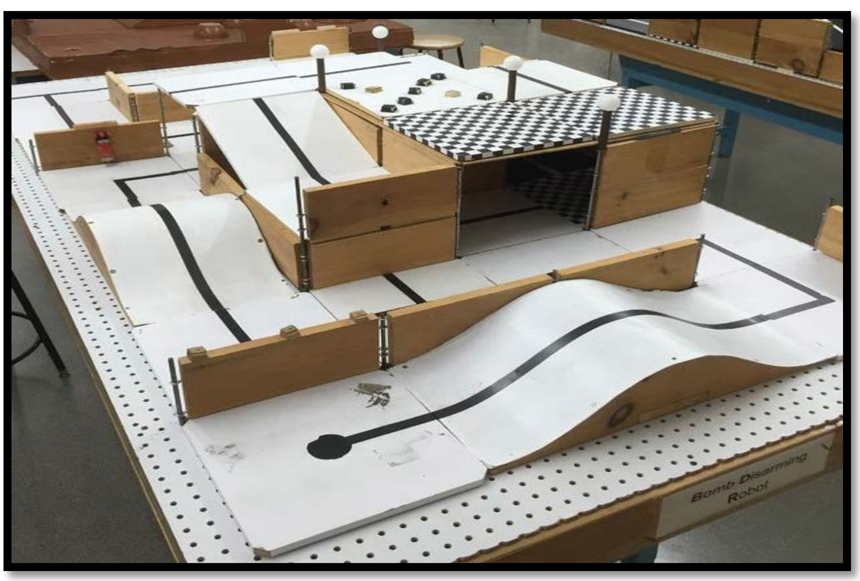

Figure 2: Autonomous Robot Terrain with Obstacles that Represent Real World Scenarios

In addition to the engineering design process, this video discusses some general CAD skills and principles. The narrative of the video relates the engineering design process and the use these CAD skills to help solve problems with the course project. Figure 3 is a screenshot that shows some of the representative basic drafting tools discussed in the video.

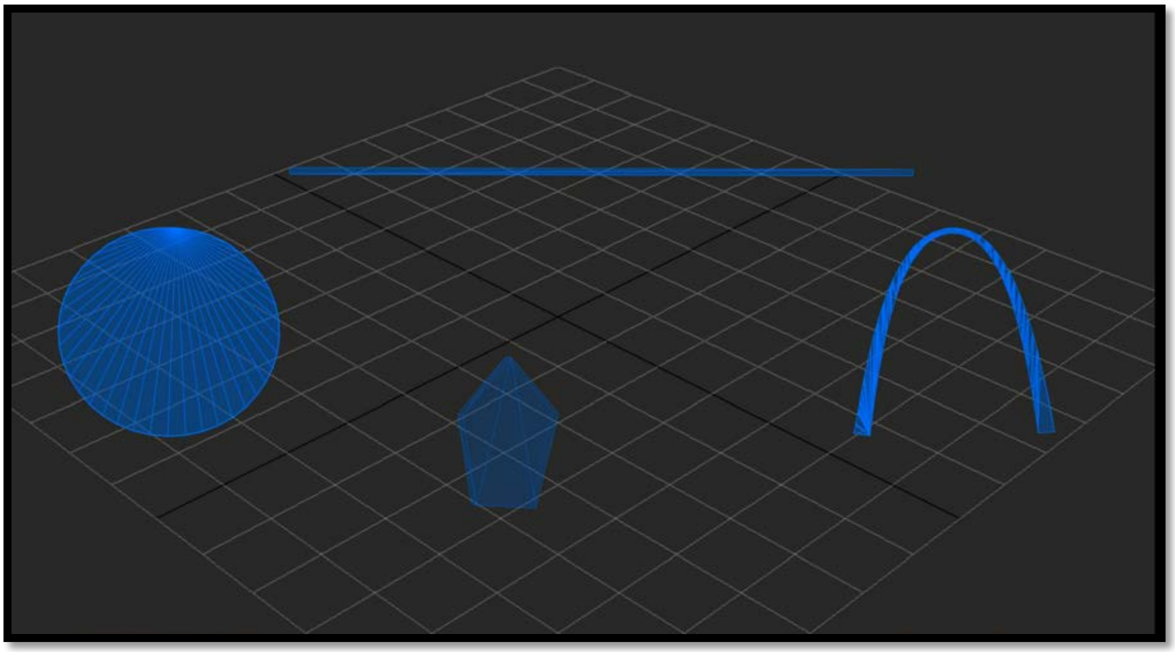

Figure 3: Screenshot from Video Demonstrating Basic 3D Modeling Skills

The results for this research paper focus on a comprehensive survey of over 300 students enrolled in the course from the end of the Fall 2016 semester. Questions were asked about the effectiveness of the instruction, quality of the video production, opinions on the video series for the class, use of the video, and recommendations. The entire survey is documented in the Appendix. A reliability analysis of the survey Likert scale questions resulted in a Cronbach's Alpha of 0.96, which is considered excellent (Gliem, 2003). Both Likert scale questions and open-ended questions were analyzed. The online streaming service for the video was used to determine analytics for viewing of the video. Grades of the quizzes and lab reports associated with the videos also helped determine if the learning objectives of the video were met.

This survey was designed with two different perspectives in mind. The perspective of the instructor focused on the student outcomes and the perspective of the video instruction team concentrated on the effectiveness of the video production. The authors have found that it is critical to consider both the instructional impacts and the medium’s effectiveness. Although many consider the video production to be an afterthought in a flipped classroom, the authors have seen significant difference in student reaction based on the quality of the video. In the literature, Johanes & Lagerstrom (2016) have found that significant planning is essential to a quality instructional video. Similarly, Abulencia et al. (2016) found there is a substantial difference in reception and longevity between a video of high production quality and videos made by students on a mobile device.

Analysis

For the past three semesters, the instructional videos have been integrated into the introduction to engineering course. During Fall 2015, only the first video was used and this resource was introduced to students as a supplement to their largely text-based lab manual. The first video was not mandatory during the first semester and the preliminary study relied on student self-motivation to access and experiment with this new video resource. In Spring 2016, closed captioning and pre-lab quizzes were added to take into account feedback from student surveys and research methods for the flipped lab model. In Fall 2016, a new video was created to focus on topics that students and instructional staff identified as appropriate and timely for the curriculum. The instructional team also wished to continue the ongoing video series. The implementation timeline per semester are outlined in Table 2.

Table 2: Timeline of Semesters for Video Implementation

Parameters	**Fall 2015**	**Spring 2016**	**Fall 2016**
Introduction to the NI Elvis Board video	**X**	**X**	**X**
3D Modeling and Design video			**X**
Mandatory viewing			**X**
Closed captioning		**X**	**X**
Pre-lab video quiz		**X**	**X**
Comprehensive Survey			**X**

Initial assessment in this study concentrated on gathering qualitative recommendations for future work and reviewing early quantitative data on student's usage of the video resources. The study will continue to look at both assessment measures to draw conclusions and determine the effectiveness of videos in the first-year engineering curriculum.

Video analytics from Fall 2015 for the 300 student engineering design course showed 234 views on the first video with an average view time of 2:09 minutes on the university video streaming system. Compared to Fall 2016 with the equivalent class size, the first and second video generated 459 and 427 views with average view times of 3:21 and 2:26, respectively. This indicates a significant increase in the number of students viewing the video resource and number of times viewed. The average percentage of the length of the videos viewed by students jumped above 50% while the first video in Fall 2015 measured at 39%. Table 3 outlines the full analytics for the two videos over semesters of equivalent enrollment.

Table 3: Video Viewing Analytics for Fall 2015 and Fall 2016

Video Analytics	**Fall 2015**	**Fall 2016**
Video 1**: *Introduction to the NI Elvis Board***		
Length	**5:36 Min**	**5:36 Min**
Views	**234**	**459**
Unique Views	**116 (50% of Total Views)**	**244 (57% of Total Views)**
Average View Time	**2:09 Min**	**3:21 Min**
View Drop Off*	**39%**	**60%**
Video 2: ***3D Modeling and Design***		
Length	--	**4:16 Min**
Views	--	**427**
Unique Views	--	**263 (57% of Total Views)**
Average View Time	--	**2:26 Min**
View Drop Off*	--	**54%**

*View drop off is equal to the average % of the video viewed by students

The mandatory viewing enforced by administering a pre-lab video quiz to students likely contributed to the increase in viewership. Interestingly, the first video was also posted on YouTube initially to make the resource available to students on a familiar viewing platform and to present this first prototype of the lab instruction video to a wider audience for testing. After three semesters, the total views on this video increased to 2,937 views on YouTube. This indicates an interest for these instructional videos outside the course for which they were created. The YouTube views justify using an external, social network platform for distribution when others may be interested in the video resource.

In a preliminary survey after debuting the first video, 30 of 67 students (45%) approved of the video's usefulness. Although, only 18% of the enrolled students responded to this initial survey, it did provide data to assess the initiative. The positive reception also encouraged the instructional team to continue the design and implementation of the video series. Another question asked students to identify future video topics that they would like to have available to them and this was compared with topics identified by faculty and the on-campus support center for teaching and learning. Interestingly, many of the topics reported by each group were the same. Faculty, staff, and teaching assistants wanted to focus on software, concepts, and equipment while students indicated software and programming fundamentals were at the top of their list. This information provided the instructional team with ideas for developing the video resource series.

For the next round of assessment, a formal survey was designed to measure student's interest in instructional videos, the usefulness and effectiveness of videos, and the connection of videos to learning or motivation. Students were surveyed after implementation of the second video of the series. Overall, the sample size for the formal survey was small and future efforts will concentrate on increasing student response rates. Out of 17 students who responded, 12 (71%) favored the use of instructional videos in the first-year engineering course and 5 (29%) did not like it.

When asked to rate (on a scale of 1-5) the 3D modeling instruction video under five categories including *Usefulness*, the percentage of ratings >= 3 is 65%. In a comparison of the same question asked about usefulness on the preliminary survey, the results are more positive after the second video. Figure 4 displays this data for the five categories. *Quality, Audio, Visual Cues, Usefulness,* and *Relevance* had 80% of responses >= 3.

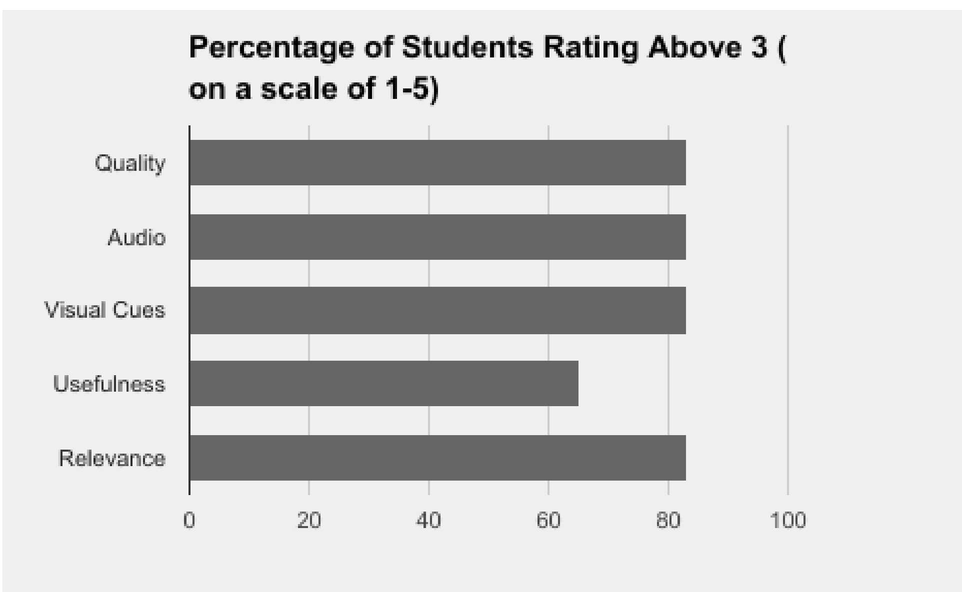

Figure 4: Rating the 3D Modeling Instruction Video

Another section on the formal survey asked students to share some insight on their learning experience related to watching the 3D modeling video and the effectiveness of the tool's components. The questions and students responses to the Likert Scale questions are detailed in Figure 5.

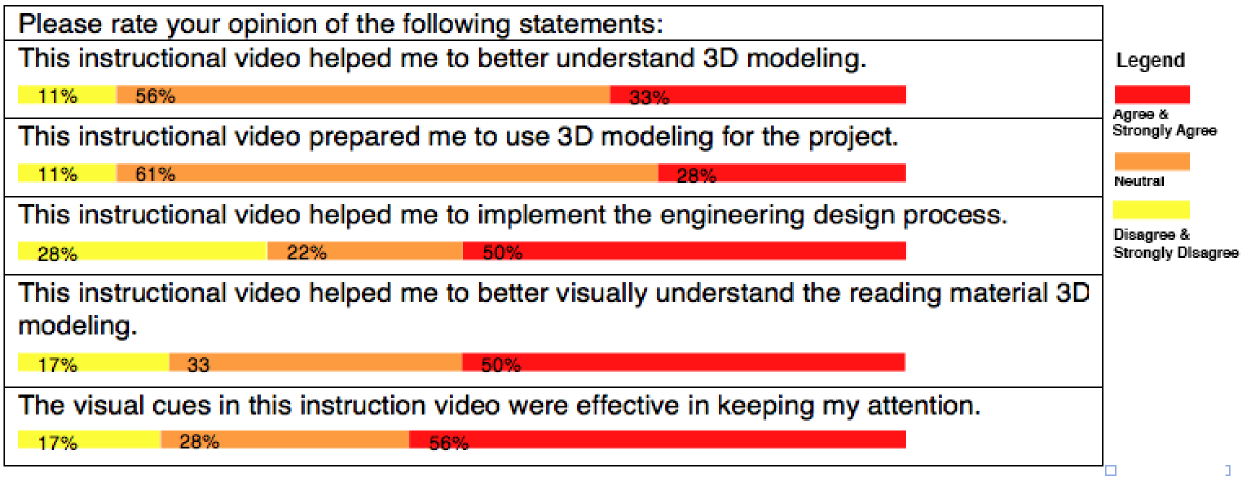

Figure 5: Survey Responses on Video Tool Effectiveness

Figure 5 shows a significant percentage (50-56%) of students, agree or strongly agree with the effectiveness of the 3D modeling video in helping them to implement the engineering design concept, visually understand the readings, and keeping their attention. This indicates that a large portion of the students have a better grasp of the engineering design process, which was one of the major goals of developing this video.

The authors also wanted to see an improvement in the creativity that students used through the engineering design process, 3D modeling, and 3D printing. The 3D printing assignment in the course was related to the design project. Since 3D printing is in the process of being incorporated into the class, it has only been extra credit, to work out potential problems before making it a mandatory assignment. The extra credit was made available in two different ways. The teams could print a 3D company logo and attach it to their robot (2 points extra credit) or the teams could create a custom robot part or a part that modifies their robot's terrain (6 points extra credit), like the sample obstacle course in Figure 1. The more advanced design of a robot part or terrain modification requires creativity because it must address an obstacle in the course and be incorporated into the code of the autonomous robot. In the first year of 3D printing assignments a larger percentage of students only attempted the team logo. After the video on 3D printing was added to the course there was a significant increase in the percentage of students that completed the more difficult, creative 3D print – Table 4 and Figure 6. This indicates that students felt more capable of attempting the more difficult 3D printing assignment after the viewing the video.

Table 4: 3D Printed Completed Extra Credit Assignments

Semester	*Team Logo*	*Robot Part or Terrain Modification*	Students Enrolled
Fall 2015	109 (30%)	7 (2%)	368
Spring 2016	28 (24%)	6 (5%)	116
Fall 2016	66 (22%)	29 (10%)	301

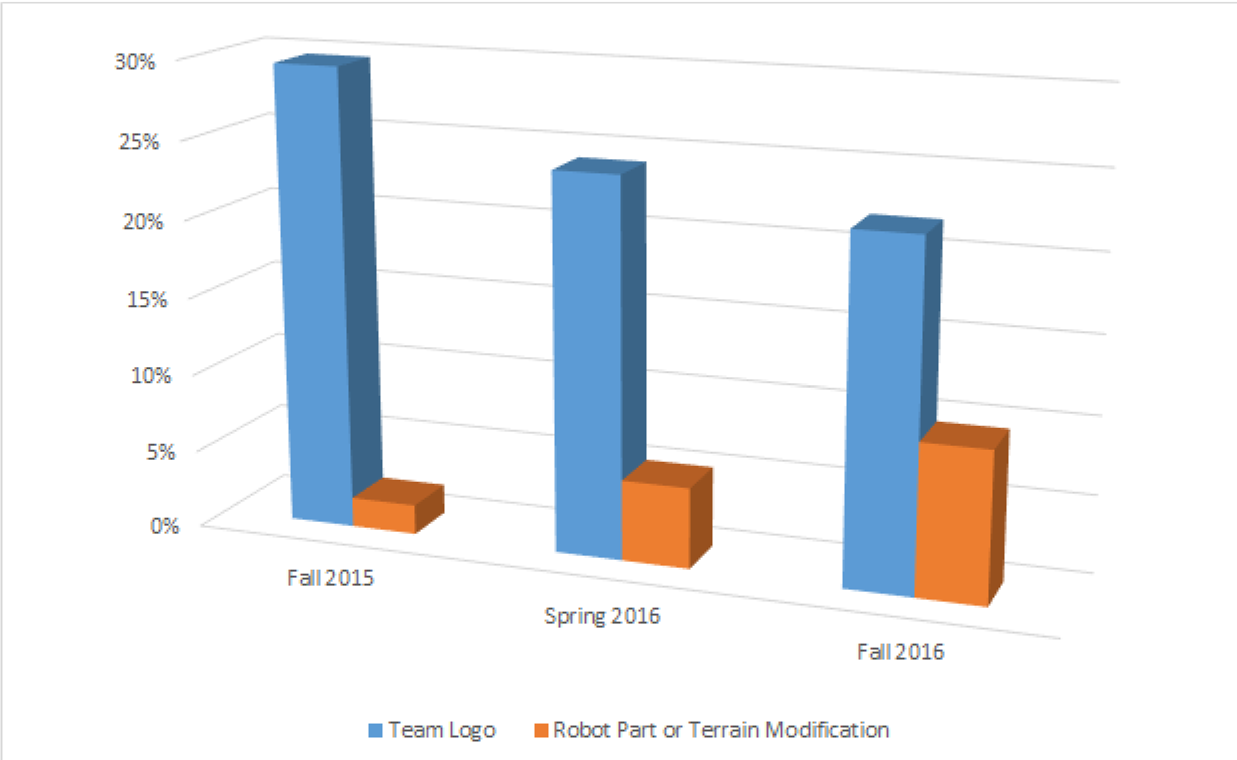

Figure 6: Percentage of Students that Completed the 3D Printing Assignments by Type

Table 5 and Figure 7 summarize the average student grades on assignments relevant to the instructional videos. There appears to be no correlation between the grade outcomes and the implementation or use of the videos.

Table 5: Grade on Relevant Lab Quizzes and Lab Reports

Semester	*Lab 3 Quiz*	*Lab 5 Quiz*	*Lab 5 Report*	Students Enrolled
Spring 2015	66.6	50.9	65.2	219
Fall 2015	84.8	57.0	73.1	368
Spring 2016	58.9	62.3	64.6	116
Fall 2016	76.1	53.7	69.0	301

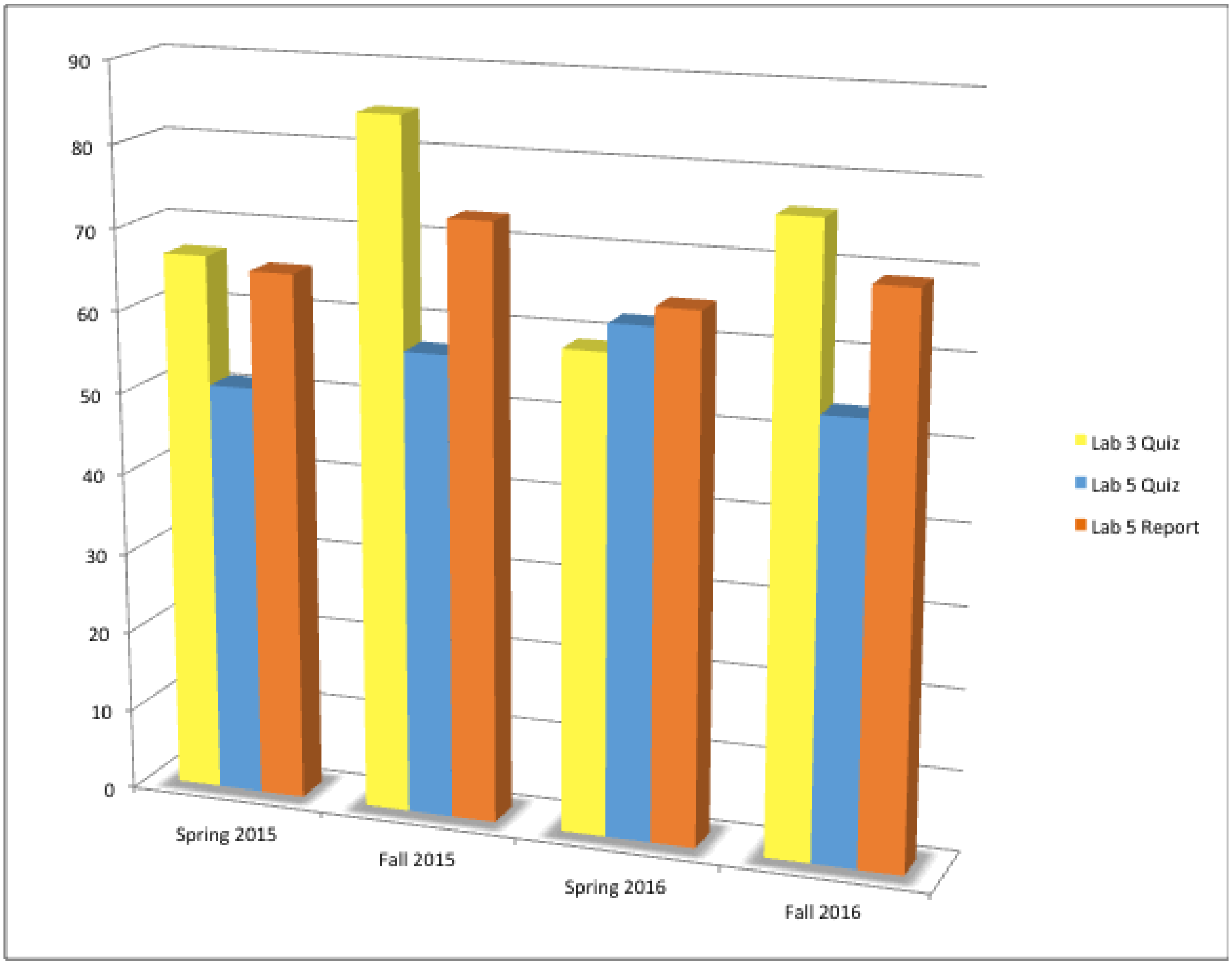

Figure 7: Grade on Relevant Lab Quizzes and Lab Reports

The lack of evidence in grades improving or student performance changing may be a result of the design behind the lab quiz and lab report rubrics. Future assessment will seek to align the quiz and report rubric grading to support the learning objectives addressed by the videos.

Below are some representative comments from students in the open-ended response questions:

What did you like about the video?
They set an example of one could use something (such as an example of how someone would implement digital logic on a breadboard)
Being actually shown what to do is a lot easier than reading a paragraph on what to do, and also more memorable - with a video, I can usually remember everything I need to after one watch, and if I forget something, it is easy to re-find a specific portion of video to watch For reading, I generally don't absorb the information until I'm actually doing it, and I have to read it while I'm doing my lab
It wasn't too long or too technical, straight to the point
The visual animations were well done in a way that was interactive.

What are your suggestions to improve the video?
Showing the transition from concept to implementation should be clearer, as well as bringing up frequently asked questions to make certain parts of the video more understandable.
Narration is not engaging and difficult to hear
It was just really... Unenthusiastic. It felt like the students were forced to do it, or like that were falling asleep.

What topics would you like to see in future videos?
Show the competition examples.
If the level of overall quality was increased, it would be awesome to watch a video instead of (or as an option instead of), reading the whole manual.
Labview, especially when described in text, is difficult to figure out for those not previously exposed to the program. a video to describe it may be more helpful than text.
All topics!

These responses show the videos were capable of being interactive and more effective for some students than readings alone. They also show they are short and with a narrow focus to keep students engaged. Some of the negative comments reveal the importance of enthusiasm to keep students engaged. However, some students felt that the videos were so effective that they would prefer the whole lab manual or course be converted to video.

Conclusion

Based on a literature review of instructional video implementation, the instructional team for these introduction to engineering course videos feel that they are applying best practices. This includes using short videos, focused topics, and extensive planning. Two videos have been created so far on breadboarding and 3D modeling. A series of other videos are scheduled to be produced, including the second part of the 3D modeling video with a focus on 3D printing and completing the engineering design process. The instructional team has conducted surveys to receive feedback on the video implementation in the course and guide future video production.

Student reception of the video has been mostly positive. The number of views each semester is greater than the total enrollment for the course, and further investigation in the streaming service shows some students are watching the videos multiple times. Survey results indicate that students get more out of the video with respect to concepts like the engineering design process than from skills such as using CAD software. The instructional team intentionally focused on these conceptual topics because of the availability of online videos with procedural step-by-step instructions on software. Instead, the instructional videos teach students how to apply the tools, resources, and software in the context of the labs and projects.

Barriers to the effective implementation of the video include the number of sections and different professors who are teaching the course. Not all professors are discussing the videos in their sections to complement the instruction that students should be receiving online. The instructors will work to improve consistency between sections. Quizzes and report rubrics will also be improved to assess the learning objectives of the videos.

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Appendix

Q1 Please rate your opinion of the following statements.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
This instructional video helped me to better understand 3D modeling.	1	2	3	4	5
This instructional video prepared me to use 3D modeling for the project.	1	2	3	4	5
This instructional video helped me to implement the engineering design process.	1	2	3	4	5
This instructional video helped me to better visually understanding the reading material for the 3D modeling assignments.	1	2	3	4	5
The visual cues in this instruction video was effective in keeping my attention.	1	2	3	4	5

Q2 Rate the 3D modeling instruction video on a scale of 1-5:

	1	2	3	4	5
Quality	1	2	3	4	5
Audio	1	2	3	4	5
Visual Cues	1	2	3	4	5
Usefulness	1	2	3	4	5
Relevance	1	2	3	4	5

Q3 Do you like using the instructional videos in this course?
a) Yes
b) No

Q4 How many times did you watch the video?
a) 1-2 times
b) 3-4 times
c) More than 4 times

Q5 How often did you watch the video (select all that apply)?
a) Outside of class, before going to the Lab
b) Outside of class, before starting the Lab
c) Outside of class, after finishing the Lab
d) Outside of class, after attending Lab

Q6 What was effective in keeping my attention on the video content (select all that apply)?
a) Imagery
b) Audio
c) Narrator
d) Flow
e) Concepts

Q7 Did you encounter any technical issues viewing the video (select all that apply)?
a) Yes, accessing from my laptop
b) Yes, accessing from my mobile device
c) Yes, accessing from a public computer
d) Yes, when I download the video
e) No

Q8 On average, how many minutes do you spend reading the lab manual as preparation before coming to class?

Q9 On average, when watching the video, how many minutes of the video did you watch?

Q10 What did you like about the video?

Q11 What are your suggestions to improve the video?

Q12 What topics would you like to see in future videos?