2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #32637

Development of Innovative, Adaptable Video Learning Modules for the Civil Engineering Classroom

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Abstract

As engineering and technology continue to evolve, so should the use of such innovations in engineering pedagogy. Standard course learning modules have not often utilized technology to assist in learning of engineering principles and concepts; that is, until the COVID-19 pandemic required teachers and students to use technology more frequently in a virtual teaching/learning environment. Therefore, it is even more critical now that engineering pedagogy be adapted to incorporate technology in the classroom to enhance student learning of complex engineering concepts. In this study, a team of Civil Engineering professors has set out to incorporate technology into their classrooms to help students gain a stronger understanding of the fundamental building blocks of Civil Engineering. A series of comprehensive educational video and simulation-based learning modules were created for the Civil Engineering subdisciplines of environmental, geotechnical, transportation, and structural engineering. The development and implementation of such technology-based learning modules offer new opportunities to teach students the complex concepts of Civil Engineering through visual means. The efficacy of the learning modules were evaluated through student assessment surveys for: (1) the appropriateness of the module in aiding the introduction of course content, (2) the effectiveness of the module in enhancing student understanding of course content, and (3) the overall perception of students of the module. Implementation of the modules into the classroom has shown that students responded positively to the modules, referencing the modules as both engaging and comprehensive in aiding their understanding of course content.

1.0 Introduction

In the engineering classroom, standard course learning modules do not often capture the innovations in engineering pedagogy and technology that are crucial for preparing the next generation of engineers for the ever-changing engineering workplace. Civil and Environmental Engineering (CEE) undergraduate students typically take multiple core courses in their junior and senior years, focusing on the five main subdisciplines of CEE, including environmental, geotechnical, transportation, structural, and water resources engineering. Courses in these five subdisciplines primarily focus on teaching modules that include traditional standards, methods, and regulations used in CEE, which are vital to a clear understanding of the fundamentals of CEE. However, these standard methods do not often capture the complex advances in engineering pedagogy and technology that will prepare students for the demands of the engineering workplace upon graduation.

In the current teaching/learning environment of the COVID-19 pandemic, teachers and students are required to use technology more frequently and adapt to this new virtual environment abruptly, as many schools throughout the world are closed and students are learning remotely from their homes with limited resources. Teachers are required to adapt their courses and learning modules to fit this virtual environment, often limited by available resources for online/remote teaching. Therefore, it is even more critical now that engineering pedagogy incorporate new technology in the classroom to enhance student learning of complex engineering concepts through visual media.

Research shows that communication errors within the classroom often arise due to misunderstanding of limited visual material and/or diagrams used to discuss complex problems, such that 3-D problems are limited by representation in 2-D space [1-2, 10]. This research especially holds true for the engineering classroom. Such misunderstanding can prove problematic for students, as evidence indicates that visual aids are instrumental in enforcing subject matter [4, 7]. If visual aids are limited by small-scale, 2-D visuals and/or diagrams, students can easily misunderstand how the concepts translate to large-scale, 3-D, real-world applications. According to the literature, incorporating more complex visual material using educational video animations and digital imaging, for example, into the classroom has allowed for students to more accurately visualize intricate, 3-D problems that are instrumental in reinforcing difficult concepts taught in an engineering classroom [5, 7, 10].

Results also show that such educational video learning modules can provide a rewarding learning experience that would otherwise be difficult for students to obtain and retain [1]. One such study that incorporated video-based instruction into the STEM classroom indicated that students found the video-based instructional modules helpful, and student quiz scores increased after reviewing the video demonstrations [10]. Another study also showed that student quiz and exam scores increased following the implementation of animations and videos into a geotechnical engineering course in the Civil Engineering curriculum [3]. Several other studies have also found that student scores increased following implementation of an enhanced visual explanation of course content in both science and engineering classrooms through the use of video and animation learning modules [1, 7, 10].

Overall, research has shown that incremental learning, scaffolding, visual aids, and repetition enforces subject matter [4, 7]. Therefore, in this study, a team of Civil Engineering educators developed a series of learning modules using video and simulation software and techniques to implement into their Civil Engineering courses in the subdiscipline areas of environmental, geotechnical, transportation, and structural engineering. Learning modules were piloted in the classrooms during the Fall 2020 and Spring 2021 semesters. Thus far, learning modules were implemented into the following Civil Engineering courses:

- Environmental Engineering I (undergraduate-level)
- Engineering Geology and Rock Engineering (graduate-level)

As this is an ongoing study, additional learning modules will be implemented into the courses of the study team during the Spring and Fall 2021 semesters and beyond. Assessment surveys will be given to students to gather additional results as more learning modules are implemented into the Civil Engineering courses listed in the following section.

2.0 Methodology

The study team utilized video and simulation software and techniques to develop a series of learning modules for the Civil Engineering classroom that would aid in student learning of complex engineering concepts. The methodology of this study consisted of two stages: 1) development of learning modules for implementation into the classroom and 2) development of assessment survey questions to evaluate students' responses to the learning modules.

2.1 Development of Learning Modules

Learning modules were developed for four subdisciplines of Civil Engineering based on the study team's areas of teaching expertise. Learning modules were designed for the following core courses in each of these subdisciplines:

- *Environmental Engineering:* Environmental Engineering I; Pollutant Fate and Transport Principles; and Sustainable Civil and Environmental Engineering
- *Geotechnical Engineering:* Geotechnical Engineering; Foundation Engineering; and Engineering Geology and Rock Engineering
- *Transportation Engineering:* Transportation Engineering; Elements of Transportation Engineering; and Transportation Safety Systems
- *Structural Engineering:* Civil Engineering Materials; Solid Mechanics; and Structural Analysis

Various methods and technologies were used to develop the learning modules for this study. Videos were created using a camcorder, tripod, and attachable microphone. Video footage was then edited using the iMovie software, a video editing software provided by Apple that allows for high-quality editing and overlay of voice recordings. Animation- and simulation-based videos were developed using the Moovly software, an online video editing software that has an extended library of existing images, videos, and simulation techniques to allow for easy usage and development. The Moovly software offers several different versions of its software that allow for the creation of longer videos, larger disposal of images and videos, and a computer-generated text-to-speech option. The software and tools used to develop the learning modules were chosen, as they are easy to use and accessible to all teachers and students without a steep learning curve. Thus far, several learning modules have been completed throughout this study and are detailed in the coming sections separated by Civil Engineering subdiscipline.

Environmental Engineering

For the Environmental Engineering classroom, several video learning modules were developed to demonstrate various topics of Environmental Engineering (Fig. 1). First, an instructional video was created to demonstrate the proper procedures for field testing of water quality parameters, as a large component of Environmental Engineering is performing water quality monitoring in the field (Figs. 1a-1b). This video was created in order to show students firsthand how to conduct water quality testing in the field. This video was shown to the students after (and within the same week) the students participated in an in-person laboratory class period where the students experimentally measured water quality parameters. Prior to reviewing this module, the students were briefly introduced to the various water quality parameters that can be measured in the field and the advantages of field testing. Two additional videos were created to introduce students to two topics relevant to water and wastewater treatment, including nutrients and bacteria. These modules were shown to the students prior to the in-person laboratory class period pertaining to the experimental measurement of nutrients and bacteria in water and wastewater, respectively. Video content included information regarding the importance of nutrients and bacteria in the wastewater treatment process, how nutrients (Fig. 1c) and bacteria (Fig. 1d) are measured and then treated and removed through the process, and the environmental and human health effects of high concentrations on nutrients and bacteria in water supplies. These videos also included simulation visuals showing how nutrients and bacteria travel through a wastewater treatment plant.

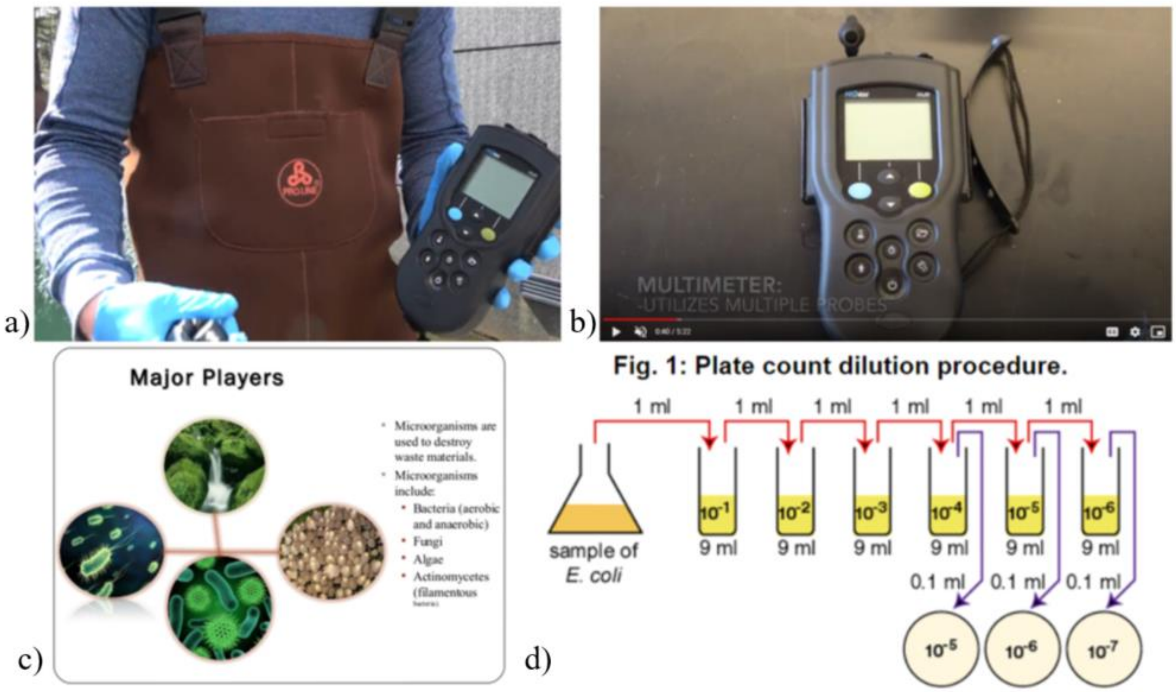


Fig. 1. Example screenshots from the various video learning modules developed for the Environmental Engineering classroom.

Geotechnical Engineering

For the Geotechnical Engineering classroom, several video and simulation-based learning modules were developed to help students conceptualize various topics of Geotechnical Engineering (Fig. 2). These video modules were introduced to the students at the beginning of the corresponding virtual class period, while the simulation module was assigned as a group project after the lecture was completed. Figure 2a shows students a comparison between two classical theories for earth pressure calculation. Figure 2b is a video at small-scale prepared by the study team to demonstrate the concept of soil liquefaction and its impact on the stability of the overlying structure. Three animated videos were made to introduce a number of topics, including the types of driven piles (Fig. 2c), the construction of drilled shaft foundations (Fig. 2d), and the technique of tunneling (Fig. 2e). These animated videos are ideal for the subject matter due to the inability for replication in a laboratory or classroom setting. Figure 2f shows a numerical simulation model developed by students to analyze the stability of a tunnel with the presence of rock discontinuities taken into account. The animated videos offer the ability to display real-world examples of each topic while also clearly displaying some of the design factors and equations that would be used in the design process.

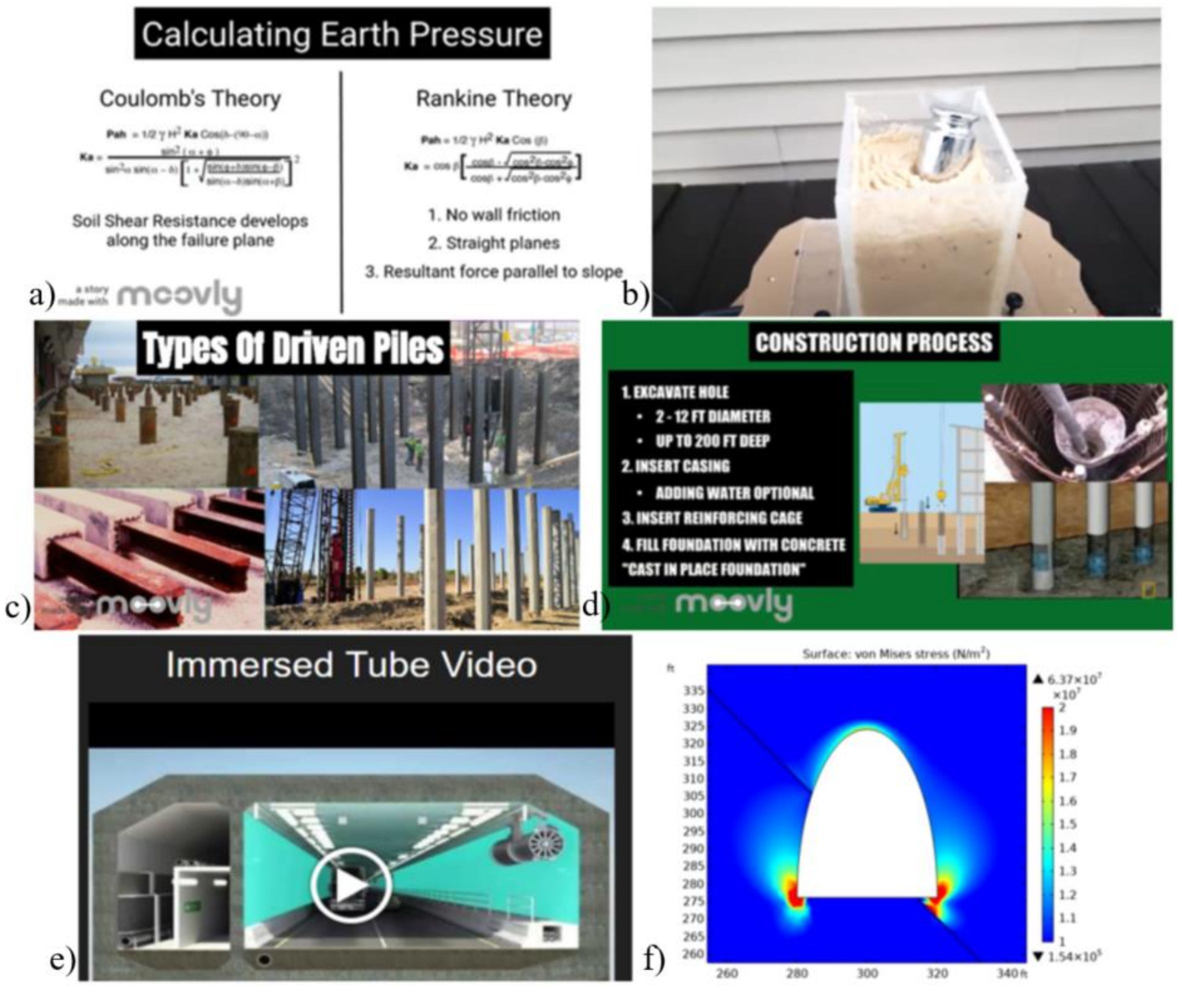


Fig. 2. Example screenshots from the various video and simulation-based learning modules developed for the Geotechnical Engineering classroom.

Transportation Engineering

For the Transportation Engineering classroom, several video and animation-based learning modules were developed for various topics of Transportation Engineering (Fig. 3). Such learning modules were created to demonstrate the roadway design process, as well as exemplify the ways that preventative laws and transportation design can mitigate the chances of distracted driving crashes (Figs. 3a-3b) and wrong-way driving crashes (Figs. 3c-3d), which are the most lethal form of crashes on the road. Much of the Transportation Engineering course content is often difficult to visualize without detailed drawings and is hard to simulate in real-time and at a large scale in the classroom. Animations and simulations can provide a means for students to visualize traffic pathways, patterns, and vehicle interactions in real-time and at a large scale. A visual animation video module was also created to illustrate the effects of the roadway and roadside elements on traffic operations and safety. All modules were provided to the students after the corresponding content was covered in the virtual class lectures as a means of reviewing the concepts before the students started the corresponding assignments.

Fig. 3. Example screenshots from the various video and animation-based learning modules developed for the Transportation Engineering classroom.

<u>Structural Engineering</u>

For the Structural Engineering classroom, a video laboratory learning module was developed to visually demonstrate the various laboratory procedures and methods used by engineers to analyze concrete. The laboratory learning module demonstrated step-by-step procedures for measuring concrete permeability and the potential outcomes of concrete deterioration, which is an essential principle for understanding the potential issues that can be experienced when building with concrete (Fig. 4). Laboratory experiments demonstrated included tests for porosity, surface resistivity, bulk resistivity, and water permeability. The laboratory module was accompanied by subtitles that detailed each procedure to enhance student understanding of the laboratory methods, but also reinforce course lecture content that is integral to the understanding of concrete design and implementation. Before performing the experiments in the laboratory, the students were asked to review the laboratory module online. After studying the module, a set of review questions followed for the students to answer and assess their understanding of the module content. Figure 4 shows the experiments and procedures included in the module: top left-to-right show sample preparation (Fig. 4a) and installation of the permeability device (Fig. 4b); bottom left-to-right show sample saturation (Fig. 4c), surface electrial resistivity measurement (Fig. 4d), and bulk electrical resistivity measurement (Fig. 4e) of the concrete sample.

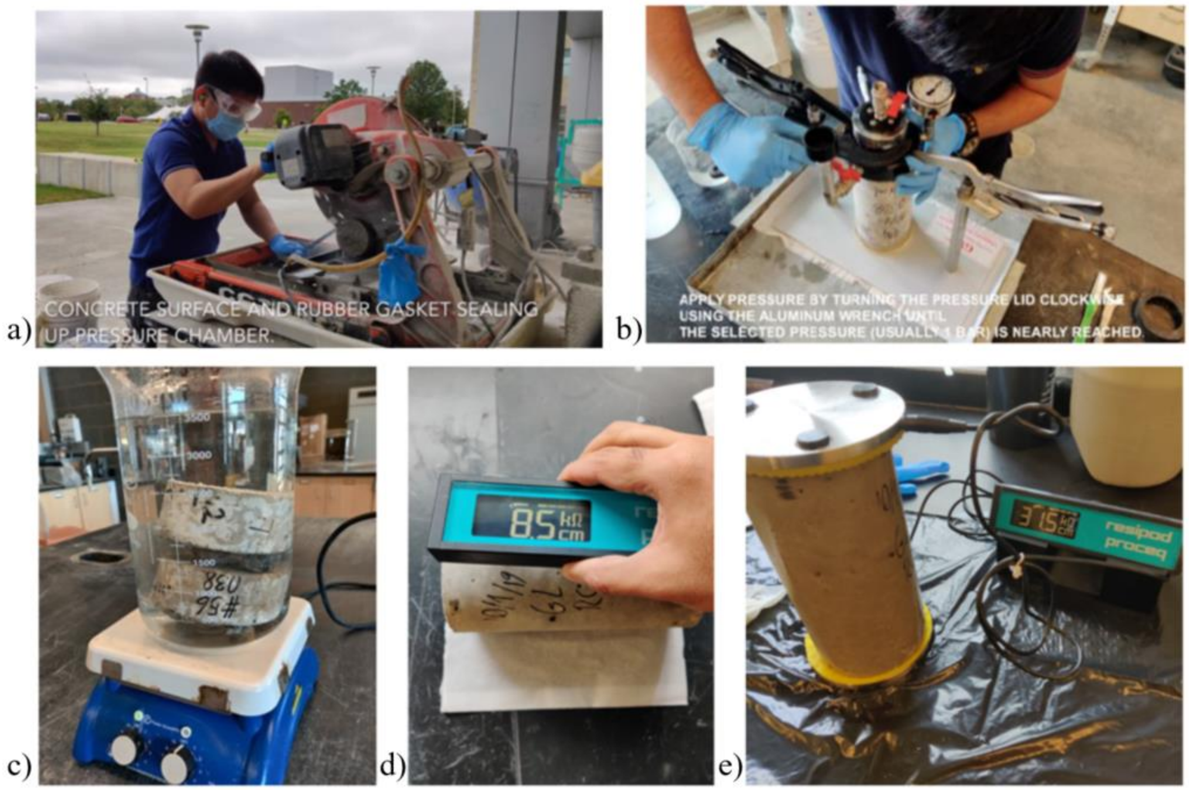
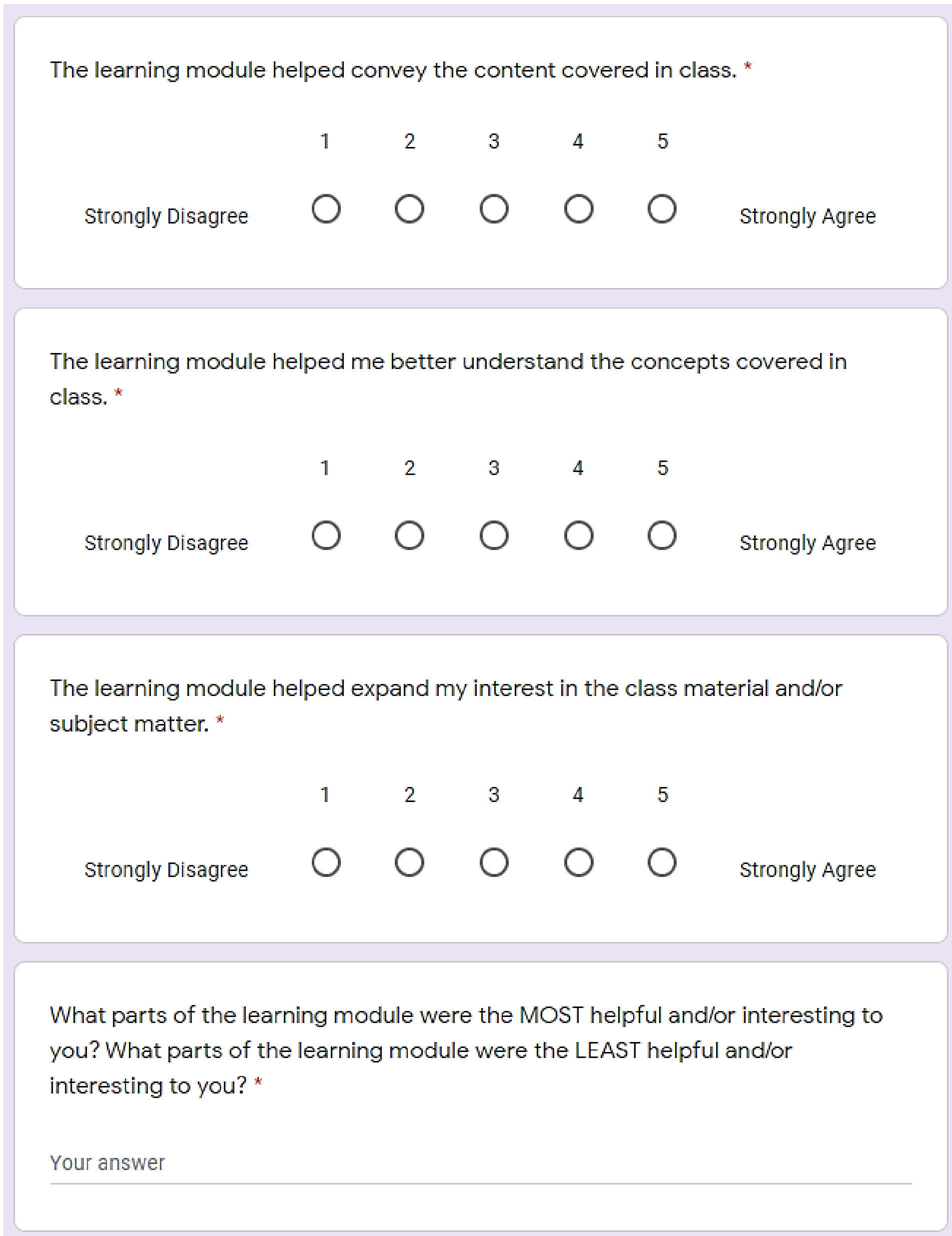


Fig. 4. Example screenshots from the various video learning modules developed for the Structural Engineering classroom.

2.2 Development of Module Assessment

A series of assessment questions were created to evaluate students' responses to the learning modules. Assessment questions were designed to assess: (1) the appropriateness of the module in aiding the introduction of course content, (2) the effectiveness of the module in enhancing student understanding of course content, and (3) the overall perception of students of the module. Survey questions were carefully prepared based on research from the literature to avoid biased wording, phrases, and leading questions [6, 8-9].

The final assessment survey consisted of three questions with available responses on a five-point scale from "strongly disagree" (i.e., 1) to "strongly agree" (i.e., 5), as well as one open-ended question which asked students to identify which part(s) of the module were most helpful to their understanding of the course material and which part(s) were least helpful. Survey questions can be seen in Figure 5. This survey was administered anonymously and voluntarily using the survey administration software Google Forms, which is part of the Google Drive web-based storage platform and was given to each student to anonymously and voluntarily complete after reviewing each of the learning modules developed for this study.



The learning module helped convey the content covered in class. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

The learning module helped me better understand the concepts covered in class. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

The learning module helped expand my interest in the class material and/or subject matter. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

What parts of the learning module were the MOST helpful and/or interesting to you? What parts of the learning module were the LEAST helpful and/or interesting to you? *

Your answer

Fig. 5. Survey questions used to evaluate the implementation of the learning modules in the Civil Engineering classroom.

3.0 Results & Discussion

In the Fall 2020 and Spring 2021 semesters, two of the developed learning modules were piloted in two Civil Engineering courses: 1) Environmental Engineering I and 2) Engineering Geology and Rock Engineering. The first course is a laboratory-based course consisting of undergraduate-level students in the third and fourth year of the program. The learning module for the Environmental Engineering I course consisted of a video created to provide a demonstration of field testing of water quality parameters in a water body. This video demonstrated the water quality testing equipment and safety equipment needed, and described the typical water quality field tests performed and how to perform those tests. This demonstration video was developed to complement an in-person laboratory exercise where students learned how to experimentally measure water quality parameters in the laboratory. The second course is a lecture-based course consisting of graduate-level students in the first or second year of their program. The learning module for the Engineering Geology and Rock Engineering course consisted of a series of animated videos created to demonstrate the three major types of tunneling methods. These animated videos provided a detailed introduction to the types of tunneling methods, applications of and advantages and disadvantages of each type, as well as potential tunneling failures.

In both courses, students were invited to anonymously complete a short assessment survey after reviewing the learning modules (Fig. 5). The results from the survey for each course are presented in Figure 6. The total enrollment and the demographics for each course are presented in Table 1. The average and standard deviation for each course are presented in Table 2.

Table 1. Enrollment and demographics information for surveyed courses.

Course	***Student Enrollment***	***Survey Responses***	***Male Students (%)***	***Female Students (%)***
Environmental Engineering I (Spring 2021) Water Quality Field Testing Video	44	38	75	25
Engineering Geology and Rock Engineering (Fall 2020) Types of Tunneling Methods Video	12	12	66	33

Table 2. Average score and standard deviation from the assessment survey results.

Course	***Total Responses***	***Average Numerical Score***		***Standard Deviation***
Environmental Engineering I (Spring 2021)	38	Q1	4.4	0.60
		Q2	4.6	0.60
		Q3	4.1	0.84
Engineering Geology and Rock Engineering (Fall 2020)	12	Q1	4.7	0.49
		Q2	4.7	0.49
		Q3	4.4	0.67

For the Environmental Engineering I course, 38 out of 44 students completed the assessment survey (86% response rate); for the Engineering Geology and Rock Engineering course, 12 out of 12 students completed the assessment survey (100% response rate). Both courses together consisted of ~65-75% male students and ~25-35% female students. Undergraduate students in the Environmental Engineering I course had limited prior knowledge on the subject area taught through the video learning module. In contrast, the graduate students in the Engineering Geology and Rock Engineering course had introductory knowledge on the subject matter.

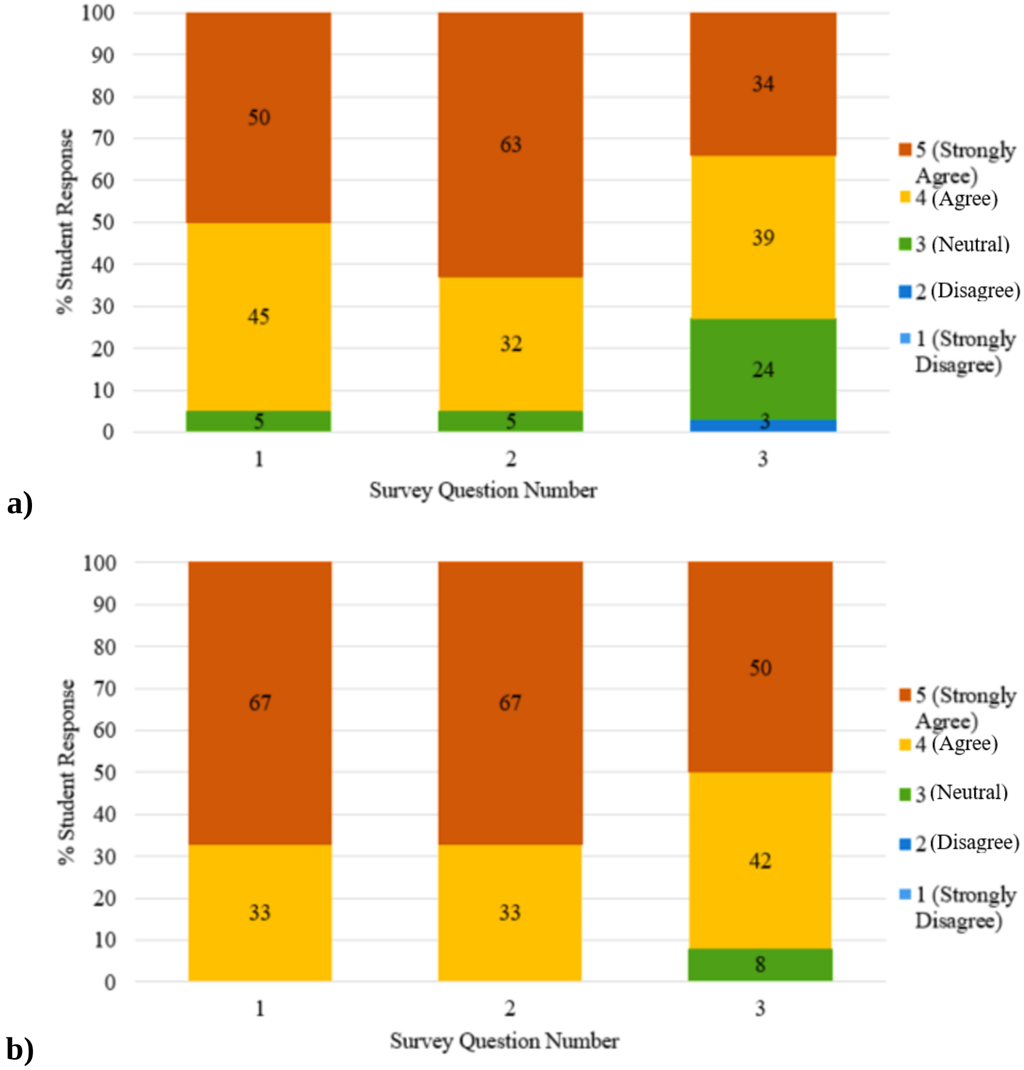


Fig. 6. Percent student responses to assessment questions for (a) Environmental Engineering I and (b) Engineering Geology and Rock Engineering.

In the assessment survey, students were asked to respond to the three main questions using a five-point scale from "strongly disagree" (i.e., 1) to "strongly agree" (i.e., 5). It can be seen from Figure 6 that the majority of the students from both courses (~95-100%) agreed that the learning modules helped convey the course content and aid in their understanding of the course concepts (Questions 1 and 2). It can also be seen that the majority of the students (though a slightly less percentage) from both courses (~73-92%) agreed that the learning modules helped expand their interest in the subject matter (Question 3). It is of interest that the responses to Question 3 of the survey were the lowest for both classes. Though the students agreed that overall the modules helped enhance their understanding of the material, not all students agreed that the modules helped expand their interest in the subject matter. In future module development, the team could add more relevant, real-world examples to the modules, for example, to help the students connect more with the modules.

For the Environmental Engineering I course (Fig. 6a), 95% of the students surveyed agreed that the video learning module helped convey the subject matter of how to conduct water quality measurements in the field and helped the students understand the methods and equipment needed to perform this analysis (with an average numerical score of 4.4 and 4.6, for Questions 1 and 2, respectively, and a standard deviation of 0.6 for both questions). In addition, 73% of the students agreed that the module helped expand their interest in water quality monitoring. This particular module was developed for this course, because in previous semesters, students expressed that they did not understand the connection between laboratory experiments and field testing procedures. After the implementation of this video module, students' overall assignment scores relevant to this course section were higher (by ~13%) than in previous semesters, showing that this module helped students to better understand this connection and the course material.

For the Engineering Geology and Rock Engineering course (Fig. 6b), 100% of the students surveyed agreed that the simulation-based video learning module helped convey the major types of tunneling methods and helped the students understand the applications of and advantages and disadvantages of each type of tunneling method (with an average numerical score of 4.7 and a standard deviation of 0.49 for both Questions 1 and 2). Additionally, 92% of students agreed that the module helped increase their interest in tunneling methods used by Geotechnical Engineers. Assuming a neutral (i.e., 3) response from the students in both courses as the null hypothesis based on previous surveys used in these courses, the average response values obtained from this survey were statistically significant ($p<0.05$), and it can be implied that educating students using video learning modules helped enhance students' learning and reinforce complex concepts of Civil Engineering.

Finally, responses to the open-ended survey question were positive for both courses. For the Environmental Engineering I course, students expressed that overall, the module was a helpful physical representation of water quality field testing methods, and was informative, helpful, and appreciated by the visual learners in the classroom. For the Engineering Geology and Rock Engineering course, students expressed that overall, the module was helpful in understanding the subject matter, interesting, and appreciated by the visual learners in the classroom. These results are promising for the implementation of additional video and simulation-based modules developed through this study into the classroom in upcoming semesters that will be accompanied by further assessment and evaluation of the efficacy of the learning modules.

4.0 Conclusions & Future Work

In this study, a team of Civil Engineering professors worked to develop a series of video learning modules to incorporate technology into their classrooms in order to help students gain a stronger understanding of the fundamental building blocks of Civil Engineering. A series of comprehensive educational videos and simulation-based learning modules were created for the Civil Engineering subdisciplines of environmental, geotechnical, transportation, and structural engineering. The efficacy of the learning modules was evaluated through student assessment surveys administrated following each learning module.

Two learning modules have been implemented into the classrooms thus far during the Fall 2020 and Spring 2021 semesters. Student assessment results show that students responded positively to the modules, referencing the modules as both engaging and comprehensive in aiding their understanding of course content. Additional learning modules are set to be incorporated into the classrooms during the Fall 2021 semester and beyond. Additional student assessment results will be collected and analyzed. In coming semesters, direct measurement assessment methods (i.e., problem-solving challenges and open-ended assessment questions) will be added to this study to measure effects on student grades. Assessment results will allow the study team to adapt and improve the learning modules to best fit the needs of the students and offer new opportunities to enhance student understanding and retention of the complex concepts of Civil Engineering through visual means.

5.0 Acknowledgment

This material is based upon work supported by the National Science Foundation (NSF) under IUSE/PFE:RED Grant No. 1623053. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of NSF.

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