Impact of pre-lab videos on improving students' learning outcomes

Ms. Resmi KrishnankuttyRema, Bowling Green State University

• Assistant teaching professor , Mechatronics Engineering Technology, at Bowling Green State University, Ohio. • Master's Degree in Bio Engineering from Georgia Institute of Technology, Atlanta, Georgia, USA. • Bachelor's degree in Electronics and medical Instrumentation from Cochin University of Science and Technology, India. • Ten years of teaching experience working as an Electronics / Mechatronics instructor of which four years in the Department of Engineering Technologies program at Bowling Green State University (Bowling Green, Ohio, USA).

• Three years of experience working as Biomedical instructor at Owens Community College.

Mr. Mikhail Shilov, Bowling Green State University

Mikhail Shilov is the instructor of Engineering Technology at Bowling Green State University who is interested in improving teaching techniques as well as mentoring and motivating students for higher achievements.

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Abstract:

In Engineering Technology courses that involve lab activities, we observed a knowledge gap among 10-30% of students that increases as the semester progresses. This places those students at a disadvantage relative to their peers, as they have difficulty understanding and mastering advanced topics. The knowledge gap also often results in the repetition of topics and prolonged lab sessions, as well as more serious issues such as the mishandling of equipment.

STEM instruction typically is based on verbal, deductive, reflective, and sequential learning methods. However, studies show that students in science and engineering programs tend to do well with visual, inductive, active, and global learning methods. With this information in mind, we developed custom pre-lab videos to address the knowledge gap. The pre-lab videos demonstrate basic usage and implementation of laboratory equipment, software tools, and commands that are used in our courses. We used these videos for instructional purposes in two different engineering technology disciplines: a freshman level course on electronics and a sophomore level course on solid modeling.

To examine the effectiveness of pre-lab videos, students' learning outcomes were assessed by conducting lab proficiency exams for the respective courses before and after implementation of the videos. We observed improvement in students' overall performance, a 20-30% reduction in the time needed to complete labs or tutorials, and the reduction of the knowledge gap as indicated by a narrower grade distribution. In addition, 10-15% more learning material was delivered, and the frequency of equipment mishandling was also reduced by 40-50%. The results of the study will be discussed in detail along with a description of how the authors have used the video tutorials for transitioning the traditional engineering technology courses to hybrid or online courses.

Introduction and Background

Several studies have shown that students learn better with hands-on laboratory activities. In the book "Learning Science and the Science of Learning," Michael. P. Clough states that **[1]**, "before addressing the role of laboratory experiences, where we wish to take students must first be articulated". For example, is the purpose of the laboratory exercise to develop a deep and long-lasting understanding of concepts or developing skills for effective science inquiry? However, even if the labs are utilized, what if there is a knowledge gap in these lab setups that results in some students falling behind the progress of their peers? As Pritzker **[2]** noted, "once a struggling science student's head dips below water, it's very hard to keep them from drowning."

In courses involving lab activities, we observed a knowledge gap that resulted in an average of 10 to 30% of students struggling to grasp the material. This gap was identified in several Engineering Technologies programs: Mechatronics Engineering Technology (ROBO), Electrical and Computer Engineering Technology (ECET), and Engineering Technology (ENGT). As the semester progresses, the growing knowledge gap puts these students at a disadvantage. Not only do some students have difficulty understanding and mastering advanced topics, the knowledge gap also often results in the repetition of topics and prolonged lab sessions, as well as more serious issues such as the mishandling of equipment.

One example of a significant knowledge gap between students was identified in the introductory ECET lab, which is required for all Engineering Technologies majors. In this course, students are exposed to the concept of electronic circuit wiring, and they are also taught how to take measurements of basic electrical parameters such as resistance, voltage, and current using a digital multi-meter (DMM). During previous semesters, instructors have noticed that a significant number of students struggle to understand and follow these concepts even after half of the semester has concluded.

Instructors of an introductory Solid Modeling class required for all students in ENGT major have also identified a knowledge gap. In this class, students work with solid modeling software using various commands necessary for constructing digital 3D solid models. However, as in the case of the ECET classes, some students struggle with the understanding and implementation of basic modeling tools. This affects further learning within this class as well as in higher level courses where the same software is used to perform advanced functions.

It was critical to address these knowledge gaps to not only improve the quality of teaching but also to improve the rates of student attrition.

STEM instruction typically is based on verbal, deductive, reflective, and sequential learning methods. However, studies show that students in science and engineering programs tend to do well with visual, inductive, active, and global learning methods [3] [4]. An approach that has been proposed and analyzed in several studies involve the use of setting up virtual laboratory facilities [5] [6]. Though, this is useful mainly in remote teaching applications, the authors believe that this is not an immediate solution for the knowledge gap observed in the courses in this study. While it would be challenging to involve all the proposed approaches at the same time, some of them were given preference, such as usage of video materials for course delivery.

The research by Nadelson and team [7] utilized a video-based demonstration of organic chemistry labs to prepare students for the lab. It was determined that the "students in control groups required 8-31 minutes longer, on average, to complete the same experiment as students in treatment groups". Overall, the authors concluded that the addition of supplemental videos "improved student efficiency and increased their knowledge in relationship to the laboratory activities." In the study by Pritzker for biology and medical students [2], they indicate a "statistically significant ($p < 0.001$) improvement in performance on exams for students who watched the videos pre-lab." The results were consistent for all the student groups in this study. While this approach is applicable to more structured science laboratories, where the precise order of steps must be followed to complete the lab, it is not as clear with laboratory activities in technology that are not always as structured.

A solution that was proposed to solve the knowledge gap problem included the development and implementation of pre-lab videos in selected courses. These videos demonstrate basic usage and implementation of laboratory equipment, software tools, and commands, and are accompanied by mandatory quizzes that are added for each topic to ensure that students viewed each pre-lab video in its entirety.

The approach that the authors followed in this study is similar to the “flipped classroom” that can be defined as a “pedagogical model in which the typical lecture and homework elements of a course are reversed” [8]. Lo and Hew indicate that a variety of methods can be used for material delivery, not only through video, but also in the form of lecture notes and reading. The authors also indicate that assignments or quizzes are used “to monitor the mastery of pre-class learning materials [9].

The approach used by the authors to address the knowledge gap has some differences compared to the reported flipped classroom methods. First, the videos that were required to be watched prior to class were short (five to seven minutes) and only introduced the main definitions and ideas that would be needed in the upcoming class. This way, the students came with the introductory knowledge, and the lecture could build on top of that knowledge. The second component that was used to address the knowledge gap, mandatory quizzes, is utilized in the flipped classroom approach as well and is designed to ensure that the students completed the pre-lab activity. It is also used to determine if there are any concepts that require additional explanations during the class time.

While there are video tutorials available online that demonstrate some of the topics covered in our classes, it is nearly impossible to find videos containing the exact combinations of equipment, lab tools, and lab assignments encountered by our students. Other issues identified with existing videos include the inability to control content by adding or removing information according to our needs, an inconsistency in video formatting and quality due to acquisition from multiple sources, and issues with long-term access to online videos due to removal by the author or removal by the host websites due to copyright violations. These limitations of existing videos will negatively affect the quality of learning and purpose of our proposed study. In contrast, custom pre-lab videos developed in house by the instructors will support student learning.

Creation and implementation of the Pre-Lab videos

Details of the courses used in the study

The following two courses were identified as the test courses for launching the pre-lab videos and conducting the study: Electrical-Electronic systems - an introductory level ECET course and Solid Modeling – an engineering design course used in ENGT and ROBO program. Both courses are considered gateway courses to their respective majors, Electrical and Computer Engineering Technology (ECET) and Engineering Technology (ENGT). The knowledge obtained in these courses serves as a strong foundation for later reference, which is why the selected courses need to be as effective as possible.

The development of videos was completed during the summer of 2018, and they were implemented as part of the course during the fall semester of 2018. The ECET course had 37 students, while the ENGT course had 21 students.

The study had two major objectives:

1) to develop a set of pre-lab videos and related quizzes explaining fundamental concepts of the test courses, and
2) to test the improvement in students' understanding of subjects using various assessment methods.

Pre-lab Video Details

For the Introductory Electronics course, seven videos were developed for aiding the lab teaching. These videos were focused on demonstrating the fundamentals of electronics circuit building and measurement of basic electrical characteristics like voltage, current, and resistance. A snapshot of the video listing used in the course is shown in figure 1.

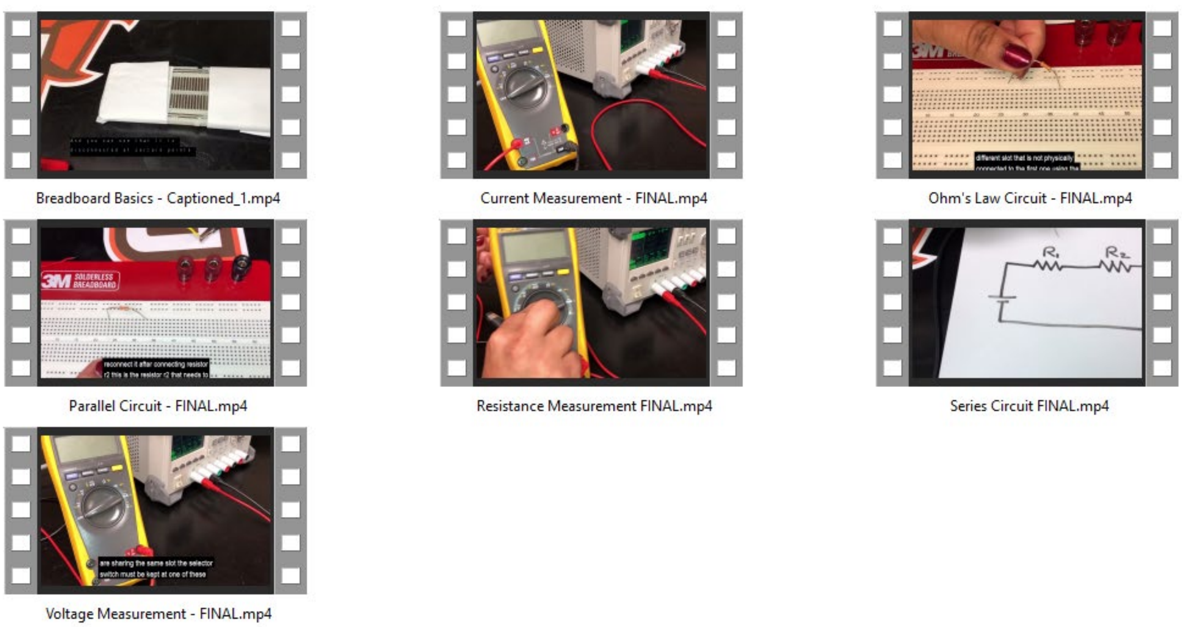

Figure1. Screenshots of the video titles used in the Introductory Electronics course

For the Solid Modeling course, ten videos were developed with corresponding quizzes. The videos explained fundamentals of solid modeling tools, sketch and feature creation, and assemblies. Examples of these videos are provided in figure 2 below as snapshots.

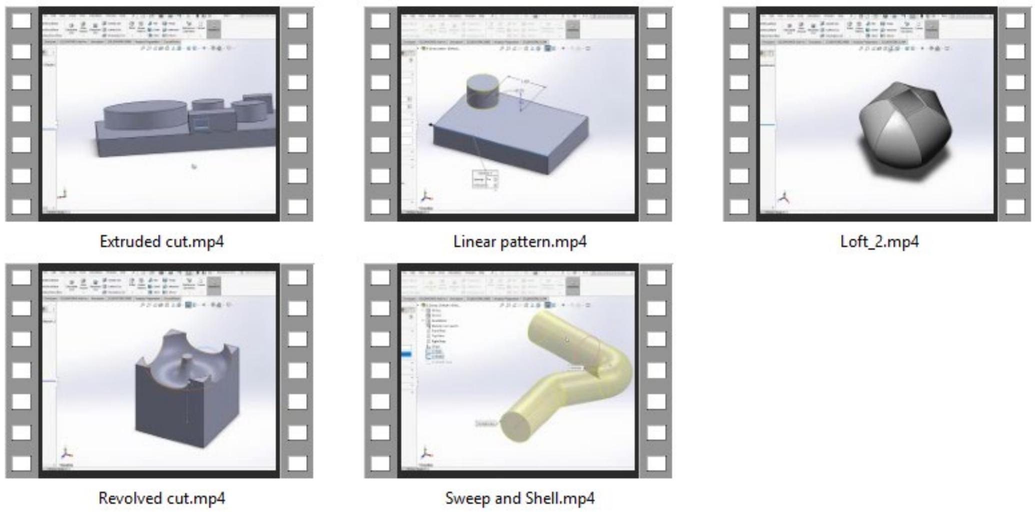

Figure 2. Screenshots of the video titles used in the Solid Modeling class

Technical details of creating the videos

The video format for each course was different, as one described the usage of equipment and the other was about the software. For the Solid Modeling class, the instructor first identified the key topics that needed to be recorded and captured screen recordings of the software while creating demo models or explaining the usage of modeling tools. Scripts were created for each video before the recording, and the narration was recorded simultaneously with the video. The audio and video recordings and editing were completed using the Camtasia studio software (https://www.techsmith.com/video-editor.html). The videos ranged in length from five to six minutes.

For the Introductory Electronics class, the instructor chose the key topics that needed to be covered in the videos, and then recorded the videos using an Apple iPhone camera. The videos were then edited using the "Final Cut Pro" software on MacBook Pro. Scripts for the audio recordings were done ahead of time, and the audio was then added to the videos as a voice over. All the videos have closed captions available in the English language to assist the viewers. The average length of the videos was kept to two to three minutes with the intention of keeping the videos short to gather maximum student attention.

Implementing the videos as part of the curriculum

The videos were uploaded to each course shell of our institution's learning management system, Canvas, before the beginning of the respective lab sessions. The videos were made available to students in the order in which they were being used in the class. So, when the semester started, only the introductory videos were available for students' reference. Other videos were released gradually as the semester progressed to eliminate any possible topic anxiety.

When the courses started, students were guided into watching the videos. They were instructed to watch the videos ahead of time, before coming to the lab. To ensure that they were in fact following these instructions, quizzes were incorporated into the Canvas shell. The students were asked to complete these mandatory quizzes corresponding to each video before the given due dates, which were before the beginning of respective labs. These quizzes were graded with minimal weightage and were made available to attempt as many times as needed until 80% score was attained. The quiz questions tested the contents of the pre-lab videos rather than the students' subject knowledge. This was done on purpose to ensure that the students viewed the videos. Student progress was monitored regularly to make sure that all students completed these mandatory quizzes before the next lab sessions.

While performing experiments pertaining to fundamental skills in each course, the videos were displayed and discussed in detail in the classroom. This gave the students an opportunity to ask any questions related to the topics at hand and helped them refresh their memory. Then students were instructed to refer to these videos as needed.

Results and discussion

Results for each course are presented separately below. However, both courses benefitted from similar advantages of pre-lab videos. Although the main purpose of pre-lab videos is to prepare students for the class, these videos need to be considered in combination with assessment tools, such as the quizzes that were used to ensure that students watched the videos and understood the material. Also, even though there are a variety of sources available on the Internet, none provide the targeted information that was considered necessary by the instructors.

In addition, before implementing the pre-lab videos, students' lack of knowledge about the equipment handling created confusion and equipment safety issues in the lab. By providing the pre-lab videos, students were able to come prepared for the lab. They were also allowed to use these videos as a reference. This allowed the students to complete the labs quicker than before and freed up time for instructors. The additional time was used for working on student projects (like soldering projects), clarifying subject-related questions, helping with course materials, etc. Students who could not come to office hours due to schedule conflicts found this additional time useful. In some occasions, the extra time was used to host guest speakers, which would otherwise not fit into the tight class schedule.

ECET course results

Before the implementation of the project, a lab proficiency exam was conducted during the fall semester of 2017. At that point, the students were expected to show 100% proficiency in their circuit building and testing skills. However, the class average on the test was only 93.6%. Furthermore, a student survey was also conducted in fall of 2017 in a successor course of the Introductory Electronics course (this was a sophomore level ECET course) to see how confident the students were about these basic proficiency levels. The survey revealed that 10 out of 18 students (56%) mentioned that they started the second ECET course without the proper basic information either due to lack of memory or lack of proper guidance. In addition, all the 18 students who answered the survey agreed that having a pre-lab video tutorial would be advantageous to them for referencing.

In the fall of 2018, when the pre-lab videos were implemented, the following approaches were used to assess the effectiveness of the study. For the Introductory Electronics course, a lab proficiency exam was conducted around week five of each of the three semesters the study was conducted — fall 2018, spring 2019, and fall 2019. The difficulty level of this exam was similar to the control group performed at the end of the semester in the fall of 2017. The test results were then compared to the results from fall 2017 to determine the improvement in students' laboratory performance after implementing pre-lab videos. Detailed results are provided below.

In the fall of 2017, the average score was 93.6% with a standard deviation of 1.38, but in the fall of 2018, when the pre-lab videos were implemented, the average score was 99.5% with a standard deviation of 0.89. The difference between these two means is statistically significant, which indicated the improvement of results when pre-lab videos were implemented. Additional data was obtained in later semesters as well. In the spring of 2019, the average lab exam score was 99.94% and, in the fall of 2019, the average lab exam score was 98.1%. Please refer to the Table 1 for further details.

Semester	**Average Test Score**	**Standard deviation**	**Number of students**
Fall 2017	93.6%	1.38	34
Fall 2018	99.5%	0.89	37
Spring 2019	99.95%	0.16	39
Fall 2019	98.11%	0.93	36

Table 1. Lab exam results for the Introductory Electronics course.

ENGT course results

In the Solid Modeling course, the mean score for midterm exams was used as the main assessment tool. The mean score for the midterm exam was 79.95 out of 100 with a standard deviation of 11.14, and in the fall of 2018, the mean score was 82.21 with a standard deviation of 7.23. The number of students in the fall of 2017 was 15, and in the fall of 2018—21 students. The comparison of these results does not indicate a statistically significant difference, but the score improved slightly and resulted in less variation, which can be an indicator of a knowledge gap reduction. The difficulty of the 2018 midterm exam was similar or slightly higher than that of the exam in 2017. Table 2 below provides aggregated data.

Semester	**Average Test Score**	**Standard deviation**	**Number of students**
Fall 2017	79.95	11.14	15
Fall 2018	82.21	7.23	21

Table 2. Midterm exam results for the Solid Modeling course.

In the fall of 2018, the semester was changed to a 15-week length as compared to 16 weeks in the fall of 2017. Despite that, in the fall of 2018, more topics were covered (10 topics instead of 9). If using only the number of topics for this comparison, a 10% increase in the amount of material provided to the students was achieved. However, if the reduced semester length is considered, up to 15% more material could have been delivered during an additional week.

Summary of course results

The results of the data analysis show that the proposed solution delivered the following positive outcomes:

1. Reduction of the knowledge gap as indicated by the grades being closer together than before. In the Solid Modeling course, for fall 2017, the mean score for the midterm exam was 79.93 out of 100 with standard deviation of 11.14, and in the fall of 2018, the mean score for the midterm was 82.21 with a standard deviation of 7.23. Although the difference is not statistically significant, the score improved, and the variability of results reduced, which indicated the reduction of the knowledge gap.
2. Better lab proficiency in the Introductory Electronics course as indicated by the reduction of the mean score for a lab exam test. In this test, students ideally need to obtain a 100% score to show the proficiency of fundamental electronics skills. In the fall of 2017, the average score was 93.6%, but in the fall of 2018, when the pre-lab videos were implemented, the average score was 99.5%.
3. Previously, mishandling of equipment was an issue in the Introductory Electronics class; but, the implementation of pre-lab videos and quizzes led to approximately 75% reduction in spending for equipment mishandling.
4. In the Solid Modeling course, a greater amount of learning material (10-15%) was delivered in a smaller amount of time due to the reduced semester length.
5. In the Introductory Electronics course, the time to complete lab experiments was also reduced by 20 to 30% which allowed for additional material revisions and extra one-on-one time with students.

A survey was conducted to obtain students' opinions about the pre-lab quizzes at the end of the semester. The survey results show that students considered the pre-lab videos to be helpful and useful, and they would like to see a similar approach applied in other courses. The results can be seen in the table 3 below.

Both course instructors, who are the authors of this paper, noticed that implementing the videos as a pre-lab preparation enhanced the teaching quality of the classes. As mentioned above, the availability of the pre-lab videos during course sessions reduced the instructors' efforts, which provided additional class time to cover more topics and to provide more one-on-one time for the students during lab sessions.

Survey Questions	**ENGT 2100** Total% = Strongly agree + Agree (18 responses)	**ECET1960** Total% = Strongly agree + Agree (88 responses)
Pre-lab videos Pre-lab videos helped me understand the topics better	83.3 22.2+61.1	89.9 57.0+32.9
Pre-lab quizzes helped me strengthen the knowledge from the videos	72.3 16.7+55.6	74.4 40.0+34.4
I would like to have similar pre-lab videos and quizzes in other courses as well	61.1 27.8+33.3	84.2 45.0+39.2

Table 3. Survey results of students' evaluation the pre-lab videos.

Impact on student learning

These pre-lab videos cover some fundamental topics of electronics and mechanical engineering. Therefore, these videos could always serve the students as a useful lab reference. There are other benefits of pre-lab video implementation:

- When students transfer from other institutions and their laboratory arrangements are not the same, these videos can then be used to facilitate an easier transition for those students. As a result, student retention could be improved as well.
- When graduate student assistants are hired to assist with instruction of laboratory sections, their lack of previous training and/or unfamiliarity with laboratory arrangements have created some difficulty in the past. In such situations, these videos could be used as part of graduate assistant laboratory training.
- Also, these videos could be used as a reference for adjunct instructors. This will ensure that consistency is being maintained with respect to student learning outcomes for all the course sections. Students will be delivered the same amount of content and with the same quality in all the sections.

The use of mandatory pre-lab videos as a pre-requisite for lab activities could be adopted by any STEM course instructors. For example, a pre-lab video demonstrating the setup of physics or chemistry experiment equipment could improve student performance. In some STEM courses with multiple lab sections taught by various instructors, pre-lab videos could be used to ensure that all the student learning outcomes are being met consistently. While some courses can be offered online, some STEM courses that include a lab component still need face-to-face interaction with students. Hybrid courses are a solution in such situations. As the authors have successfully demonstrated, the development of video tutorials could facilitate the transition of selected courses within majors to a hybrid teaching format that could be beneficial to the students.

Conclusion

The implementation of pre-lab videos has proven to be an effective method of reducing the knowledge gap. The results show that it is a more efficient method as well since less time is needed to deliver the same amount of material with the same or higher assessment of student learning outcomes. Although the initial investment of time required to develop such materials could be relatively large, students will be more prepared for upcoming labs and future classes.

In addition to the knowledge gap reduction, pre-lab videos allow for more learning material to be delivered during the semester, they also improve the safety of the labs and even spending on equipment maintenance. The usage of quizzes ensures that the students watch the videos, and short duration of videos keeps them engaged throughout the semester.

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