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Prompting by COVID-19 to Rethink the Purpose of Engineering Laboratory Education - Develop Practical Competence to Solve Real-World Problems

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ABSTRACT

Today's engineering laboratory education often lacks opportunities for students to practice critical thinking through real-world problems. This particular objective is even harder to achieve through online laboratory experiments. In this article, we summarize our innovation in using a real-world challenge, analyze big data, to empower student data analysis skills in remote teaching platform. This approach allows students to collect data, analyze, and evaluate possible solutions continuously through hands-on experimentation with accessible resources around them. Compared to the video-recorded lab, our method achieves a higher level of learning in Bloom's taxonomy. To further improve our approach, we summarize our lesson learned from transferring six different engineering laboratory courses online, in response to the COVID-19. A thriving 21st-century learning environment has to embrace agility, create flexibility, adapt to technology, and support virtual team collaborations.

Key words: Laboratory, Problem based learning, Critical thinking

INTRODUCTION

One major challenge in 21st-century engineering laboratory education is fostering students' critical thinking skills[1]. Today's labs often lack opportunities to solve complex real-world problems because students often work on artificially-defined activities with little connection to today's challenges. The purpose of labs in undergraduate engineering education continuously evolves in our changing world[2], from a heavy focus on hands-on practicum in the 19th century to theory-driven approaches in the 21st century. However, recent literature shows that theory-driven labs provide little to no measurable benefit in improving students' understanding of basic science and engineering principles[3]. So, we asked: what is the purpose of an engineering laboratory in the 21st century?

The ABET/Sloan Colloquy[4] identified that the objective of engineering education laboratories is to promote student cognitive, psychomotor, and affective skills[2]. In the past year, the Penn State Department of Mechanical Engineering initiated faculty discussions for modernizing the undergraduate curriculum to promote student cognitive skills. The intention is to distill our existing lab courses into a new problem-based laboratory course. At the same time, a thorough renovation of space for a new dual-purpose teaching and maker-space facility is underway. The new course will encompass advanced topics, e.g., energy, sustainability, big data, and autonomous robotics. Students will examine and scaffold complex problems, apply foundational knowledge, and evaluate possible ways to solve problems through hands-on experimentation.

In light of COVID-19, we observed an urgent need to redesign our traditional lab courses to provide interactive materials, which are engaging and allow students to perform hands-on experimentation with accessible resources. We took this situation as an opportunity to pilot one of the experiments in our new problem-based laboratory course. The particular experiment introduces big data principles by using statistics to classify human activities. Students use a smartphone to gather motion data, perform data analysis and processing, then classify human activities by machine learning algorithms. It is the first experiment in our cognitive training sequence in which we are following Bloom's Taxonomy of Learning.

In this article, we document our innovation in using machine learning, a rapidly growing field, to educate our students on relevant courses online in response to COVID-19 and proposed steps to enhancing teaching effectiveness.

METHOD

We have created a machine learning module focused on basic statistics, data analysis techniques, and basic machine learning concepts using MATLAB live script. The goal of the project is to identify five human activities using x, y, and z accelerometer data. The training separated into five steps, which are summarized in Table 1.

Table 1. Workflow of the MATLAB Machine Learning Module.

Steps	Student Tasks
1	Review of basic statistics and MATLAB coding.
2	Apply statistics knowledge to extract features from a three-axis accelerometer dataset.
3	Review basic data structures in MATLAB. Expand the work from step 2 to process over a hundred datasets.
4	Train machine learning models to classify data, using the Classification Learner App.
5	Deploy the trained model. Use the MATLAB Mobile App to access smartphone sensors and acquire data. Make predictions of human activity and improve model accuracy.

PRELIMINARY RESULTS OF ONLINE IMPLEMENTATION

In response to the global coronavirus outbreak, Penn State decided to move to remote learning in the week of spring break. To rapidly transform our senior-level Dynamics System Laboratory course online in a week, two possible solutions were identified:

(1) video recording original experiment and providing synthetic data to students for data analysis, or

(2) replacing two dynamics experiments by the new machine learning module.

Since all original experiments were designed in a two-week format, students had started the first part before the university closure. We had provided synthetic data for students to complete their experiments in the first week of transferring online. Considering the importance of providing hands-on experiences, we implemented the second solution for the rest of the semester. Based on an anonymous survey with a 17% voluntary response rate, 6 out of 7 students prefer the machine learning module to the video recorded labs. All students are satisfied with the activity and agree that the module helps them review statistics and understand the basics of machine learning. The satisfaction and agreement were measured by 7-points Likert scale, and all questions received an average score of 6. (1 = Strongly disagree, 4 = Neutral, 7 = Strongly agree)

One major consideration in replacing the original experiments was to ensure student learning outcomes remain unchanged. We retained opportunities to develop and conduct appropriate experimentation, analyses, and interpretation of the data, as well as use of engineering judgment to draw conclusions. A detailed example is shown in Figure 1. In addition, our new material added enhancements that exercised students' critical thinking skills. As shown in Figure 2 comparison of the two lab models, a video recorded lab was not sufficient to allow students to evaluate their work and perform continuous experimentations. The machine learning lab opened up the opportunity for students to evaluate their choices, make continuous improvements, and attain a higher level of learning.

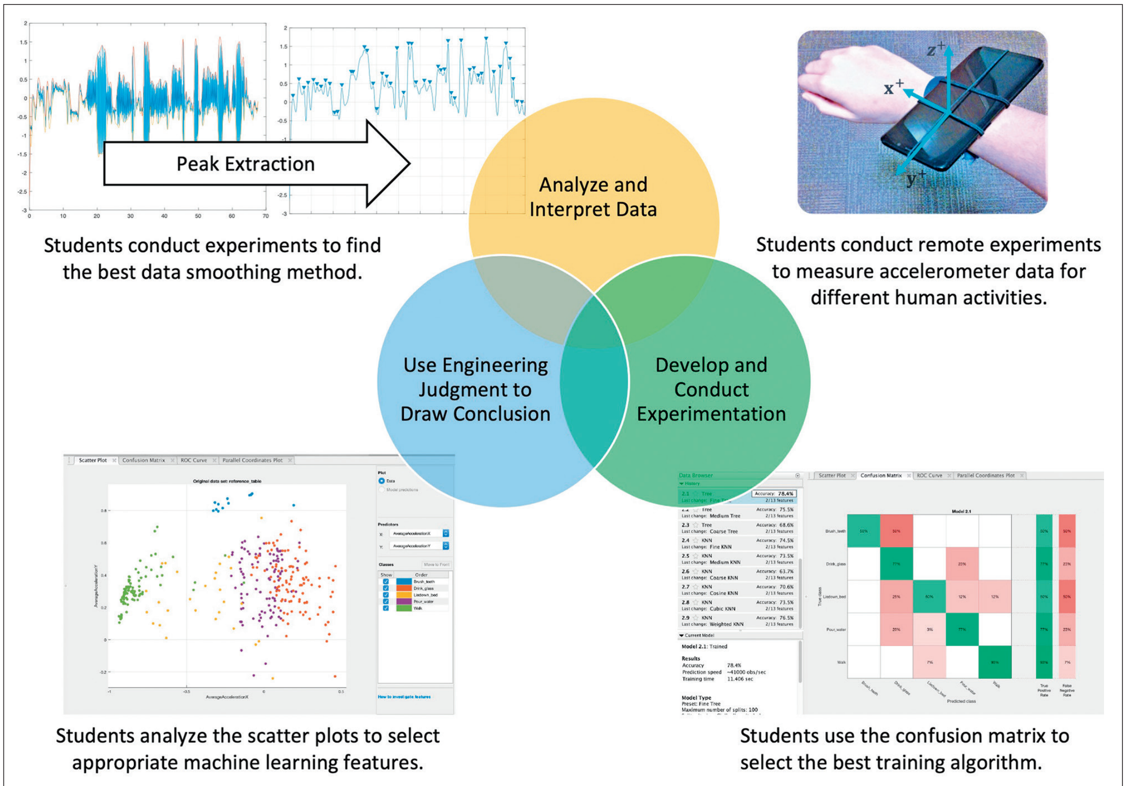

Figure 1. Example of students work to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

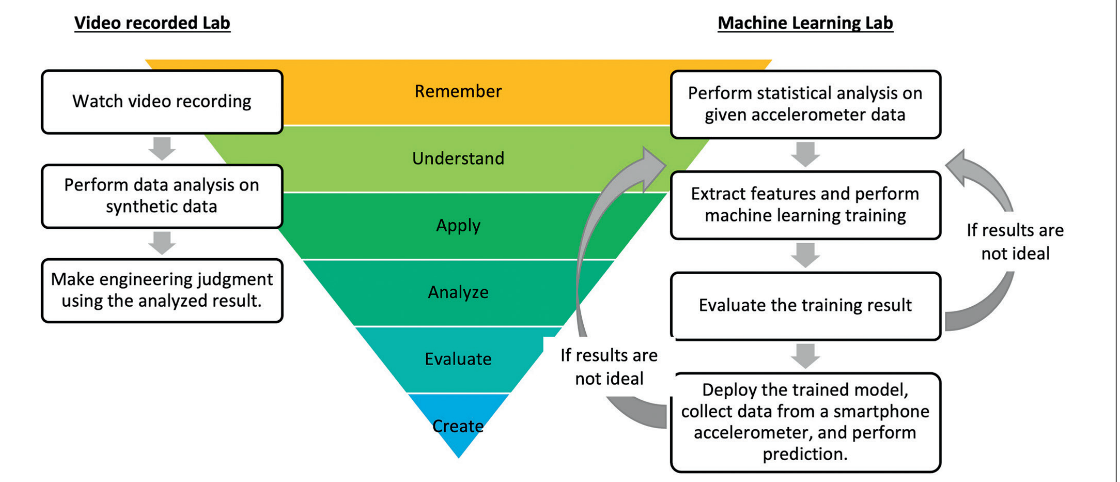

Figure 2. Comparing video recorded lab to the machine learning lab in higher-order thinking requirements.

From the students' perspective, comments made to the instructor emphasized the practical value of their learning and how their new knowledge connected to daily life. When students are interested in a topic, their engagement levels increase. A graduate teaching assistant in the course, who completed her degree from our undergraduate program made the following comment after completing the training.

> "The machine learning training forced me to sit and process how variations in data—such as walking compared to drinking water—can affect, and even create errors in, how the actual motion is predicted. I have come to see that a prediction model is not perfect; however, it is the optimization of the model that is important for getting accurate results." – A Mechanical Engineering Graduate Teaching Assistant

NEXT STEPS

A particular challenge we encountered in this pilot implementation was to support virtual teamwork. To find solutions, we gathered instructors' and graduate teaching assistants' feedback from six different engineering laboratory courses.

From the instructors' perspectives, students appreciated:

1. Timely responses, through Zoom breakout room, email, or online office hour.
2. Video recording on experiments and lecture allow students to learn at their own pace.
3. Converting experiments into virtual equivalents for experimentation.
4. Interactive activities
5. Connecting knowledge to solve a real-world problem, e.g., COVID-19

We observed similarities between a thriving learning environment and a supportive 21st century workforce environment, which include embracing agility, creating flexibility, adapting to technology, and supporting global/virtual team collaboration. In the future, we plan to apply virtual teamwork practices used in industry to our classroom. Such practices include defining roles in a team, designing virtual activities to acquaint students with each other, educating teams to self-facilitate, documenting meeting outcomes, and applying project management tools.[5,6]

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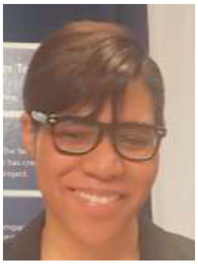

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