Online Multimedia PreLab Tutorials in Conservation Laws

Homeyra R. Sadaghiani

Department of Physics, California State Polytechnic University, Pomona, CA 91768

Abstract. Physics laboratories are intended to provide students an opportunity to investigate physical phenomena by making observations, collecting and analyzing data, and presenting their findings clearly. However, some students lack an adequate preparation and conceptual background to achieve these objectives. To help students to better prepare for the laboratory sessions at Cal Poly Pomona, in a pilot study, we designed a 20-minute online multimedia prelab tutorial on the topics of conservation laws using flash animations, narration, and videos. This multimedia prelab includes a brief lesson on the theory, as well as an introduction to the laboratory procedure and apparatus with embedded assessment questions and feedback throughout the module. The preliminary data shows improvement in student overall preparation, quiz scores, and their lab reports after using this prelab tutorial.

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INTRODUCTION

The vital role of laboratory work in the study of physics has been discussed in many different venues.[1,2] Traditionally, most physics laboratory experiments focus on student observations of physical phenomena, testing and verification of known principles, and perhaps application experiments. As a result of research on student learning and also the rapid development of new technology[3,4] in the past couple of decades, the introductory physics laboratory instruction has been evolving. For example, research-based laboratory curriculums are designed to move beyond illustration and verification of physical concepts and emphasize the role of observation in building scientific models.[5,6] Most of these laboratory experiences challenge students to construct the concepts to explain their own observations and help students utilize and synthesize physical concepts developed and tested earlier to explain new observations.

Technology brings more computer-based activities, simulation, and virtual laboratory options to physics classrooms.[7,8,9] Recent research shows that, if designed appropriately, computer simulations can be valuable tools when it comes to bridging the gap between teaching and the students' conceptual understanding of physical concepts.[10] In this paper we will discuss the use and the effectiveness of an online multimedia prelab tutorial on conservation laws.

BACKGROUND

Existing introductory physics laboratories at Cal Poly Pomona are traditional and intend to provide an environment for students to apply the principles they have learned in lecture and to test the validity of these principles. *Physics 131L, Calculus Based Mechanics Lab,* is a laboratory course that accompanies PHY 131, and is supposed to be taken concurrently with PHY 131 lecture. The three-hour weekly lab covers experiments in mechanics, kinematics, conservation laws, rotational dynamics, and static equilibrium. Every quarter, the 131 lectures and labs are offered to more than 250 students from engineering and other departments; maximum laboratory enrollment for each section is 24 students.

Most laboratory activities in this course are designed with the assumption that students have learned the relevant concepts in the lecture portion of the course; however, weekly physics lecture topics and labs are not often coupled well. As a result, students are frequently required to confirm experimentally some of the concepts not yet covered in lecture, which forces lab instructors to review or introduce the concepts that the experiment is designed to confirm. This leaves less time for students to make observations, carry out measurements, gather and analyze data, and achieve laboratory objectives successfully. Although students are expected to study the lab theory and procedures before attending each lab, in practice, they rarely read

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the lab manual prior to the lab. Students often spend class time to read the manual and familiarize themselves with the concepts and apparatus before they start the experiments. As a result, the class time is not being used efficiently. Students often do not get to complete all the measurements and analysis by the end of the class period. In addition, students' poor quality of lab reports reveal their vague understanding of the concepts they applied in their lab work.

Over 1,500 students from six different colleges and twenty-one departments are enrolled in physics laboratory courses each quarter at Cal Poly Pomona. The existing equipment is old and outdated, and space and equipment are limited. On the other hand, with the increasing cost of laboratory equipment and the enormous faculty time demand, coupled with the current budget crises the California State University system is facing, the revision of the entire introductory laboratory course is not realistic at this point. Therefore, to help students to prepare for the laboratory before coming to class and for them to use the class time more efficiently and productively, we are piloting the development of online multimedia prelab tutorials. These short multimedia materials supplement PHY131L and are designed to facilitate conceptual understanding. We have created an online tutorial on the topic of conservation laws using flash animations, narration, videos, and text. The ~20-minute tutorial contains a brief tutorial on the theory, video on the apparatus, introduction to laboratory procedures, and embedded assessment questions and feedback. The hypothesis is that by helping them to learn/review the relevant physics principles before the lab, the online tutorials would assist students to better prepare for the actual hands on activity exercises. Thus, they could devote the entire laboratory time to measurements, calculations, and data analysis.

LABORATORY EXPERIEMNT ON CONSERVED QUANTITIES

The laboratory experiment on "Conservation Quantities" is the topic of week six in PHY 131L. The motivation for developing a prelab for this topic came from the fact that not only did it receive the lowest average score of all the prelab quizzes [see **Plot 1**], but also it was more complex in its concepts and procedures compared to the previous five experiments on the course syllabus. This lab combines two physical concepts of conservation of energy and conservation of momentum in the context of two woodblocks suspended by two cords (similar to ballistic pendulums). The lab activities require a deep understanding of several physical concepts. For example, in addition to conservation laws, students need to understand the difference between elastic and inelastic collisions, as well as which conservation laws apply to each part of the experiment.

In the first part of this lab, students investigate the relationship between a pendulum at maximum height (h) and the speed of the bob at its lowest point (v_0). Students release the pendulum from a few different heights and a computer calculates the speed of the pendulum at its lowest point using a laser-gate. The relationship is given in the manual and students only confirm that the square of pendulum velocity at its lowest point is proportional to the height from which the pendulum is released:

$$m_1 gh = \frac{1}{2} m_1 {v_0}^2 \Rightarrow {v_0}^2 = 2gh \qquad (1)$$

In the second part of the experiment, one of the blocks is released from an arbitrary height; it hits the second block (stationary) and causes the two-block system to swing up together. The two blocks experience a complete inelastic collision (blocks attach each other by using pieces of Velcro). Students measure the masses of the two blocks and the laser-gate measures the speed before and after the collision.[11] Students then use these values to investigate the law of conservation of momentum:

$$m_1 v_i = (m_1 + m_2) v_f \qquad (2)$$

Finally, students compare the total momentum of the system before and after collision using various mass combinations for the incoming block and the stationary one to observe that in a complete inelastic collision, unlike the energy, the momentum of the system is conserved. The ballistic pendulum is a classic example of a collision in which conservation of momentum can be used, but conservation of energy during the collision cannot be invoked because the energy goes into inaccessible forms (e.g., internal energy). Conservation of energy can be used in the swing of the combined masses upward after the collision. For novice learners without a deep understanding of the concepts, applying the principles correctly and recognizing the limitations are challenging tasks. An additional obstacle is the fact that most students attend this lab without any prior knowledge regarding the theory, thus they use the concepts presented on the lab manual (conservation of energy, conservation of momentum, and complete inelastic collision) all at once without a robust understanding. We do not suggest that labs should follow course content and strongly believe in the effectiveness of inquiry and the self-discovery laboratory format. However, in the context of this research, the current laboratory design requires an experimental confirmation of the concepts and principles that are already given in the current laboratory manual.

THE ONLINE MULTIMEDIA PRELAB TUTORIAL

The tutorial combines interactive simulations, videos, text plus graphics, with continuous narration. Students actively make observations, interact with the simulations, and conduct virtual experiments. The tutorial contains three main parts and is presented over 12 slides. The first part briefly reviews concepts of energy and conserved forces in question and answer format. The second part is composed of three interactive simulations, and the final part is a brief video on the apparatus that familiarizes students with relevant laboratory equipment and provides helpful tips and information on the laboratory procedure. The embedded quiz questions provide timely formative feedback on student understanding.

The simulations model the laboratory work in more inquiry format and ask students to use their observations to investigate the relationship among different physical quantities presented in each of the animations.[12] The first simulation [**Figure 1**] isolates the concept of conservation of energy and allows students to control the height from which a pendulum is released and discover the relationship between a pendulum release height and its velocity at the lowest point of oscillation. The second simulation [**Figure 2**] focuses on the conservation of momentum law in a complete inelastic collision and asks students to explore this concept independently from conservation of energy concepts. Students can change initial values of speed and mass for each of the blocks, drag and collide the blocks, observe the outcome of the motion visually, and request to view the relevant calculations of the momenta and the final velocity of the two-block system. Finally, the third simulation [**Figure 3**] integrates the two conservation laws in the context similar to the lab activity. Students use the principles of conservation of energy for the incoming block to calculate the initial speed and momentum before collision (similar to the first animation) and use conservation of momentum (similar to the second animation) to calculate the final velocity of the two-block system after collision analytically (in the actual lab the final speed is measured by computer using a lease-gate.) The combined presentations, simulations, and the video on the apparatus [**Figure 4**] scaffold the intertwined laboratory concepts and intend to help student conceptual understanding. It also clarifies some of the theory and calculations behind the computer measurements of the velocities.

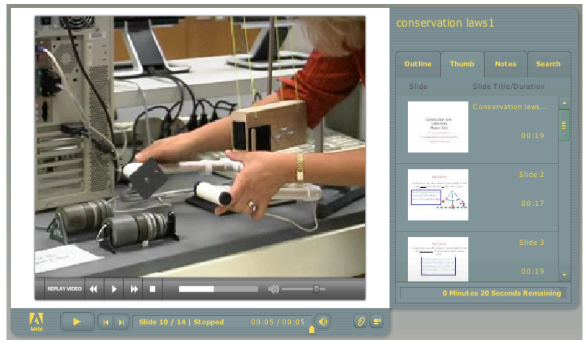


Figure 4. Screen shot of the video on the apparatus. The right side of the image shows the slide layout for the tutorial.

DATA AND ANALYSIS

Prior to implementing the multimedia prelab, we used weekly in-class prelab quizzes to encourage students to review the concepts, read the manual, and familiarize themselves with the lab equipments and procedures prior to attending class. The overall average score on the eight weekly quizzes for 120 students enrolled in five sections of this laboratory course was $54\% \pm 3\%$ [**Plot 1**]. This low score indicates that students were not well-prepared for the lab activities and lack the basic pre-requisite concepts required for their investigations. In the following quarter, after implementing the online prelab, we administered the same prelab quiz on Conserved Quantities to three new sections (n=72) in which students viewed the multimedia prelab tutorials prior to attending the lab session on this topic. The average quiz score was improved from $45\% \pm 2\%$ to $70\% \pm 2\%$. The comparison of student quiz scores on the individual twelve questions of the prelab quiz on Conserved Quantities is illustrated in **Plot 2**.

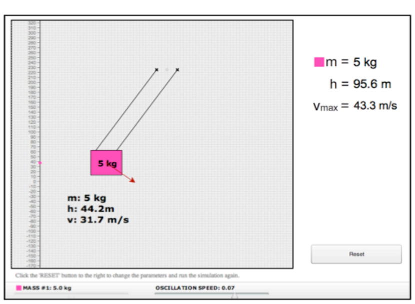


Figure 1. Screen shot of conservation of energy simulation.

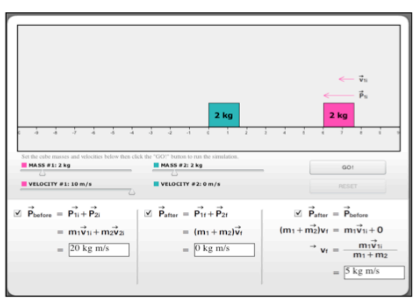


Figure 2. Screen shot of conservation of momentum simulation.

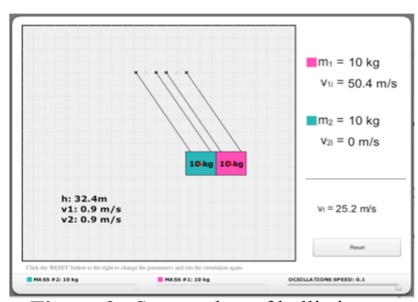
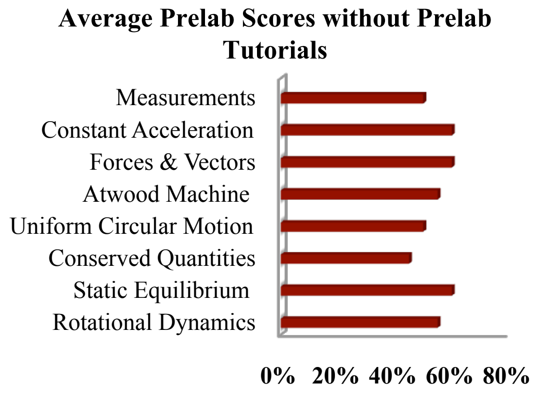
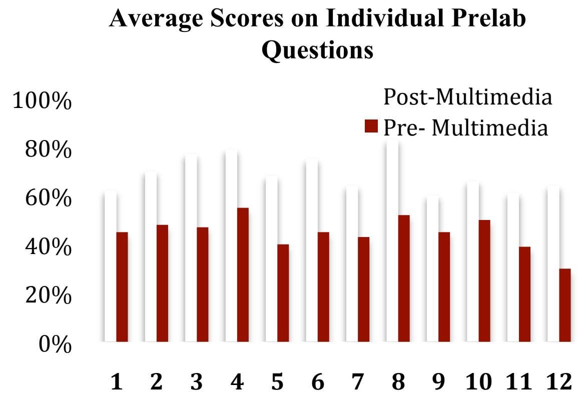


Figure 3. Screen shot of ballistic pendulums.



Plot 1. Average scores on eight prelab quizzes before any multimedia prelab tutorial was implemented.



Plot 2. Average scores on individual prelab questions before and after multimedia prelab tutorial on conservaion laws.

On a five-scale Likert survey, approximately 85% of the students indicated that simulations were helpful in understanding the relevant concepts and 75% stated that the videos were helpful in preparing them for the laboratory work. In general, students expressed positive feedback about the online multimedia prelab tutorial. Some student comments include:

"Most of the time, I don't like the labs; usually, I don't know what I am supposed to do and look around to see what others are doing, but this time was different!"

"My lecture section is always behind and I don't know the concepts we need in lab, but tutorial helped me to understand."

"Seeing the lab equipment in the video ahead of time helped me to feel more confident."

"...It (the tutorial) helped me a lot and was easier than reading the manual."

"I try to read (the manual) before lab, but don't understand without seeing the equipments, but the video helped me to understand the manual."

Without the online tutorial in place, students often spent in average 15-20 minutes reading the manual and checking out the apparatus prior to starting any measurement procedures. After the tutorial, students were ready to start at the beginning of the class and hardly referred to their manuals. In addition, the quality of the lab reports for the Conserved Quantities was evidently improved when compared to previous quarters without the online tutorial component.

DISCUSSION

The multimedia online prelab tutorial assisted students to better prepare for the actual hands on activity exercises. Thus, students could devote the entire laboratory time to measurements, calculations, and data analysis; which resulted in higher quality lab reports that could imply improved understanding of the concepts. The students found the prelab tutorial useful in helping them to understand the concepts and prepare for the laboratory experiment. This work is only a small reform and a greater structural change is needed to improve the setup of the current traditional labs to more effective inquiry format.

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[11] Perhaps, the black-box nature of the laser-gate computer measurement does not help with simplifying the problem.
[12] The simulations can be viewed at:
https://connect.csupomona.edu/pendulumsingleswf/
https://connect.csupomona.edu/impulseswf/
https://connect.csupomona.edu/pendulumswf/