

# Using IOLab to connect real-world experiences to controlled laboratory experiments

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## Abstract

Scientific experiments, by their very nature, control conditions and variables with the goal of ensuring that what the experimenters think they are testing is what is actually being tested. However, experienced scientists bring intuitions honed by their critical consideration of real-world experiences, where myriad factors contribute to the behavior that we see. Bridging this intuition gap for students can be a challenge both for the learners and instructors. By utilizing a recently-developed wireless data acquisition system, the IOLab, for pre-lab experiences where students will gather data about real-world activities for which they have extensive personal experience, we hope to increase student intuition and provide a framework for students to engage in the scientific enterprise. By the end of the course, students will develop their own novel research activities and present their results to their classmates.

## IO Lab

Developed by Mats Selen and the PER group at the University of Illinois, Urbana-Champaign, the IOLab, seen in Fig. 1, is a wireless data acquisition system which interfaces with a PC/Mac using a USB dongle from up to 100 ft away. It is small (3 cm x 7.5 cm x 13 cm) and light (less than 200 g), which makes it highly portable. The most recent version of the IOLab contains more than twenty sensors or inputs, including a 3D accelerometer, a 3D magnetometer, a 3D gyroscope, wheels which record position, velocity, and acceleration, a force probe, and both analog and digital inputs. Data can be analyzed in the IOLab program itself, or can be output to a comma separated value file for analysis in a spreadsheet or other software. [5]

Researchers at the University of Illinois have focused on using the IOLab as a tool for pre-lecture tutorials and comparing student learning using the IOLab versus reading a chapter in a traditional introductory physics textbook. During the Spring 2014 semester, we piloted the use of IOLabs within the introductory lab for experiments studying Simple Harmonic Motion, RC circuits, and Electromagnetic Induction. Student responses to the IOLabs were positive, and anecdotally, engagement was higher than during many other traditional labs. Based on the success of those experiences, we chose to go ahead with more extensive utilization of the IOLabs this Fall.



FIGURE 1. The IOLab, version 2, shown with USB dongle. Near the top of the unit are the microphone and speaker, as well as axes for alignment. The three wheels are connected to an encoder. Near the bottom of the unit are the analog and digital inputs and outputs (similar to an Arduino Uno).

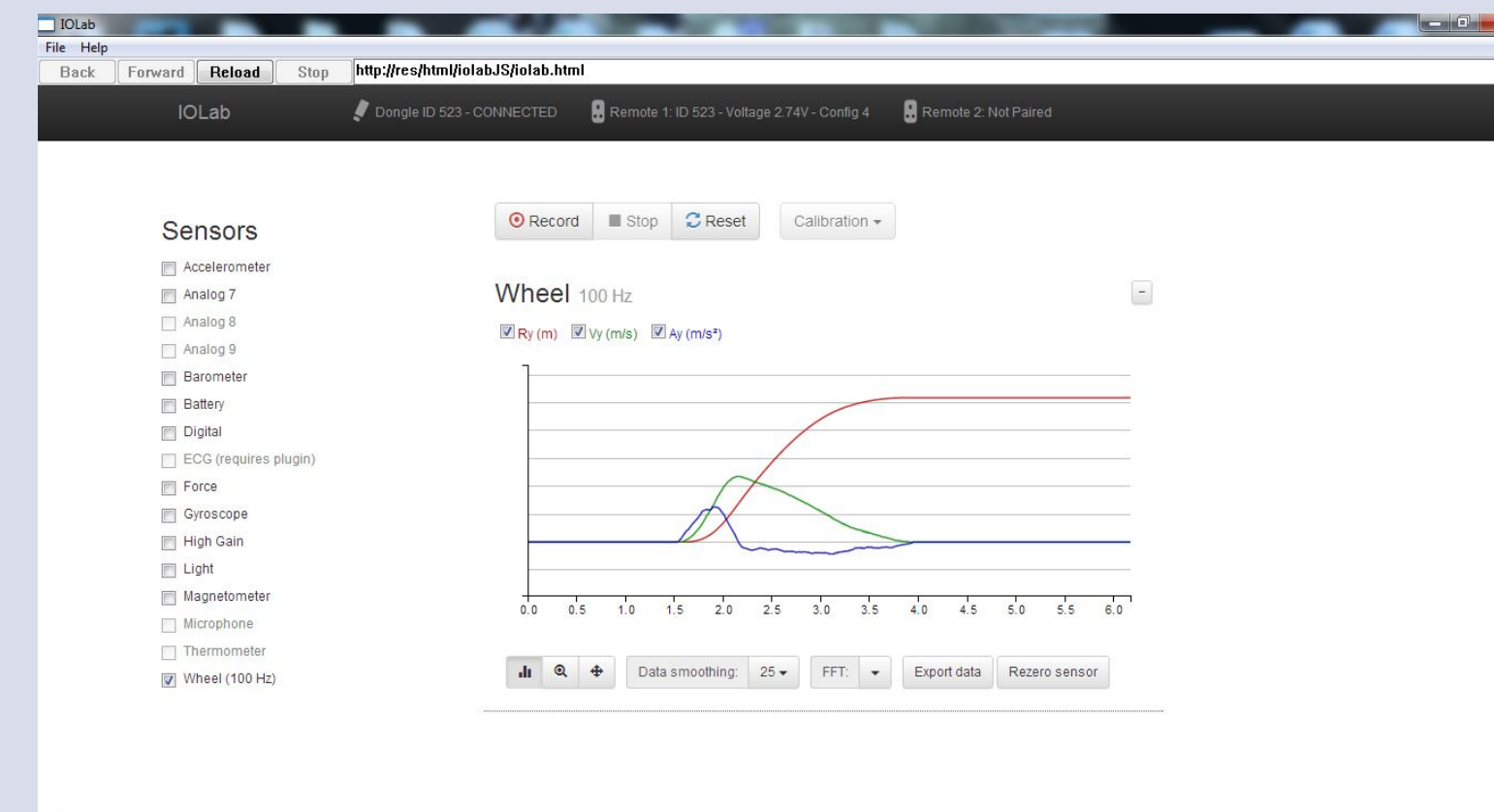


FIGURE 2. Data for the IOLab pushed from a resting start and rolling to a stop. The wheel sensor is used to measure position ( $R_y$ ), velocity ( $V_y$ ), and acceleration ( $A_y$ ). The horizontal axis is measured in seconds. The list of available sensors is on the left side of the figure.

## Pre-Lab Exercises

In the revised lab section, students will each be given their own IOLab to use during the semester (as opposed to in-lab exercises, where students will work in groups). Students will be given a short series of guiding questions to answer before and after they have completed their pre-lab exercises. Early in the semester, more guidance will be available on what to do, especially in regards to using the equipment, and the scaffolding will be reduced as the semester progresses. The guiding questions students will have for each pre-lab are as follows.

Before the pre-lab:

1. What are you trying to test?
2. What factors do you think will affect your test?
3. Which of those factors can you control, and which can you not?
4. Which sensors on the IOLab do you think will be useful for your test?

After the pre-lab:

1. Does your data look like you expected it to?
2. Are there other tests you need to perform? (If so, perform them if possible.)
3. What information can you extract from the data?
4. How does what you observed during your test(s) connect to what you've seen in class or the text?

After completing the pre-lab, each student will be required to submit a short report on their pre-lab activities by 6 AM the day of the lab, which I will review before beginning the lab period.

## Introduction

Introductory physics labs can serve a multitude of purposes, depending on the instructor and the departmental learning goals. They can be used to introduce students to the experimental nature of science, develop experimental techniques and procedures, connect theoretical material from “lecture” sections with real-world behavior, teach data-analysis (and sometimes propagation of uncertainties), show students how to model physical systems, and/or develop skills in oral and written presentation of scientific results. [1] One of the biggest challenges, given the nature of a controlled lab experiment, is to make the connection between what goes on in class and what students experience in the real world, and to help students understand the value of the lab in their learning of physics. [2,3] We use air tracks to eliminate friction, move at slow speeds to reduce the impact of air resistance, ignore masses of pulleys and strings, and make myriad other simplifications in order to make the material more “accessible” to novice students who often lack in mathematical sophistication. There are always trade-offs, however, and one of the consequences of these simplifications is that students’ intuition, grounded in the real world, can be disconnected from what they are seeing in the lab.

The goals of this project are to rethink both the purpose of the labs and consider how to connect controlled experiments in lab with real-world experiences familiar to students. In this paper, I will focus on our application of new technology, which is both easy to use with a minimum of training and versatile enough to apply to a wide variety of contexts.

## Traditional Structure of Lab

Each semester, we run two or three parallel lab sections. For logistical and scheduling reasons, students from both the algebra-based and calculus-based introductory courses can sign up for any of the lab sections, resulting in a mixture of students with a widely varying background in each lab. Labs are traditionally capped at 24, which typically allows for six four-student lab groups, although we increase the number of lab groups and decrease the number of students per group when sufficient equipment is available. Each lab meets 12 times during the semester for two hours, and is staffed by a full-time professor and usually one or more upper-division undergraduates working as lab assistants.

Students are graded on three things: lab quizzes, designed to motivate pre-lab preparation such as reading the lab manual; a lab notebook, kept as a record of their procedure, data, calculations, and results; and four lab write-ups, in which students are asked to undergo a more thorough reflective analysis process regarding their experiments and to enhance or develop their scientific communication skills. For the Fall 2014 semester, we will be running two lab sections: one which will be taught as described above, and one which will be modified as described below.

Our learning goals for a Natural Science with Laboratory course are that students will:

1. Develop an understanding of how to use logic and the scientific method to analyze the natural world and solve problems.
2. Learn about issues in science that are important both personally and globally.
3. Utilize technology in laboratory and field environments in order to connect theories and descriptions found in lectures and textbooks with real-world phenomena.

The expectation is that the first two goals will primarily be addressed during the lecture, and the third primarily in the lab.

## Revised Structure of Lab

While we will not be changing the overall learning goals for science courses at this point, the revised lab section will approach the goals differently. Instead of the lab quizzes, students will use IOLabs to perform pre-lab exercises where they will begin exploring the concepts they will study in lab, but in a real-world setting with which they have a greater experience. Pre-lab video tutorials have been shown to improve student learning, and our hope is that by making the pre-lab activity hands-on and interactive, this effect will be heightened. [4] These pre-lab exercises will be weighted more heavily than the lab quizzes to reflect the additional effort they are expected to take and the additional learning they should facilitate.

The other significant revision we will be making to the lab will be to introduce a summative experience in which students will be asked to design their own experiment and present their results to classmates. This presentation will be performed in lieu of the fourth lab write-up, which is usually due during the last week of classes.

## Examples of Possible Projects

**An object being pushed from a resting start and rolling to a stop.** In Fig. 2, the IOLab starts at rest at  $y=0$  (the wheels are oriented along the  $y$ -axis). This data could be studied in numerous ways depending on the questions being asked – how does position relate to velocity and acceleration, what force (given the mass) causes the acceleration(s), what is the coefficient of rolling friction, what impulse did the pusher impart to the IOLab, etc.

**An object dropped from rest and falling freely until caught.** Fig. 3 shows the vertical component of the acceleration. The IOLab sensors are calibrated so that the acceleration has a magnitude of  $9.8 \text{ m/s}^2$  when at rest and zero when it is in free fall. Students could ask further questions about the effect of air resistance on falling objects by varying the height of the drop, adding mass to the IOLab, attaching a parachute, etc.

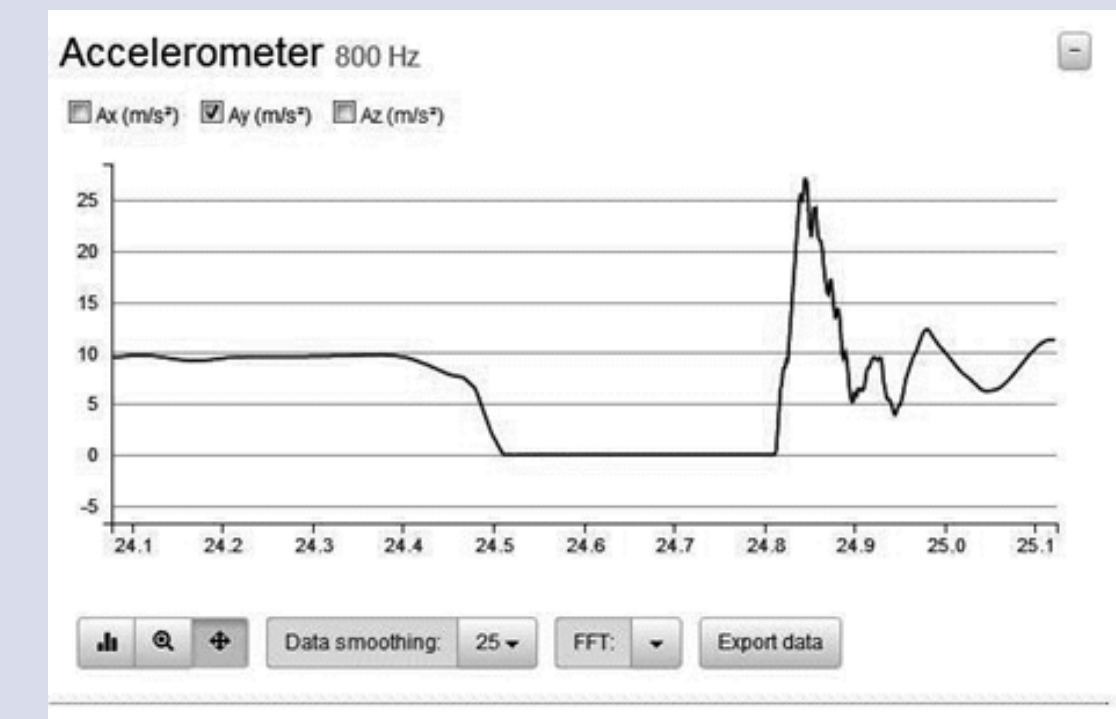


FIGURE 3. Data for the IOLab dropped from a resting start and falling freely until caught. The accelerometer sensor is used to measure the acceleration in the direction of motion ( $A_y$ ). The horizontal axis is measured in seconds.

**An object moving in simple harmonic motion.** For this example, the IOLab was placed on a child’s playground swing which was then set into motion. Fig. 4 shows the vertical component of the acceleration oscillating sinusoidally with time as the swing moves. Students could ask further questions about the effect of amplitude on period, stand on the swing while holding the IOLab to change the center of mass and nature of the pendulum (from simple to physical), etc.

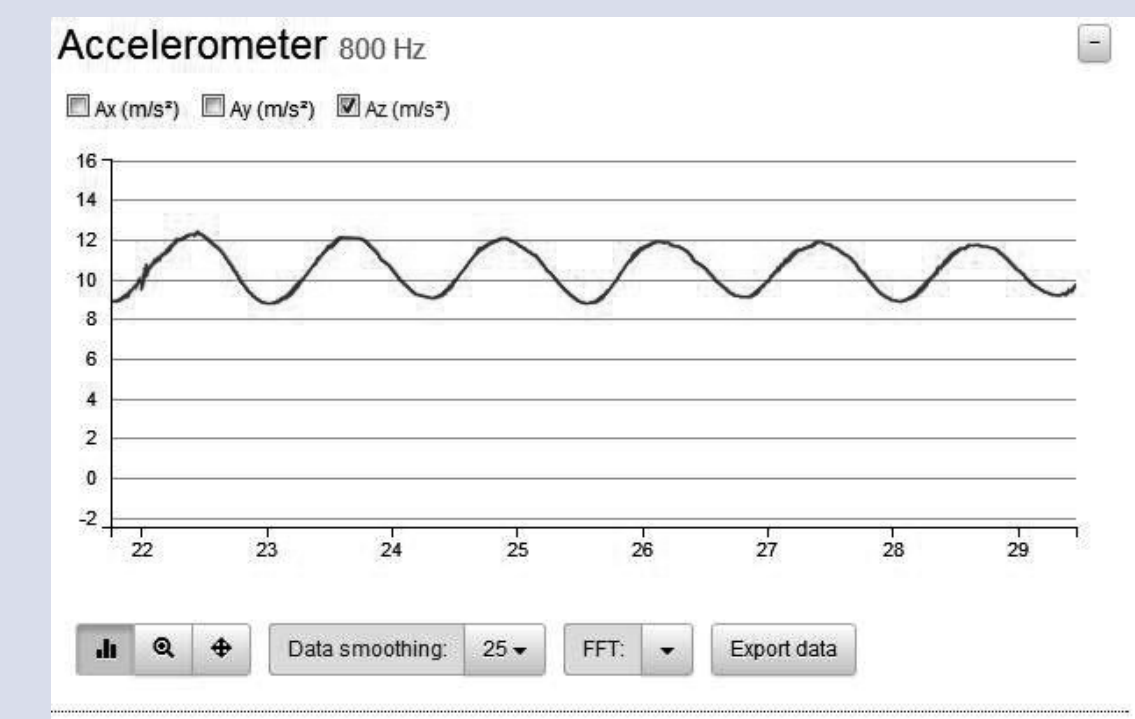


FIGURE 4. Data for the IOLab oscillating in simple harmonic motion on a child’s playground swing. The acceleration sensor is used to measure the vertical component of acceleration. The horizontal axis is measured in seconds.

## Summative Project and Assessment

At the end of the semester, students will be asked to demonstrate that they can apply the skills they have developed throughout the semester to a novel situation. For their summative project, they will need to design an experiment regarding a topic covered in class but not explicitly addressed by one of the in-lab experiments. They will submit the results of their work in a short video segment. In the video, they will be asked to describe their experiment, using the guiding questions used throughout the semester, and explain their results in the context of theories discussed in class.

At the beginning and end of the semester, we will administer the FCI as a pre- and post-test. The normalized gain will be compared between students in the revised and in the traditional lab sections in both the algebra-based and calculus-based introductory courses. An assessment of student perceptions of the value of physics and the physics lab will also be administered, again comparing results between lab sections.

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