ABSTRACT

LANZ, COLLEEN BURKE. The Educational Impact of Smartphone Implementation in Introductory Mechanics Laboratory Classes. (Under the direction of Robert Beichner and M. A. Paesler).

The internal sensors within students' smartphones are capable of collecting the data required of a traditional introductory mechanics laboratory curriculum. In these laboratories, some of the pedagogical barriers that are possibly introduced by hardware interfaces and their accompanying software might be reduced through the use of such smartphone sensors. For this reason, we have created a series of labs that exploit the many capabilities and familiarity of smartphones. The project—titled "MyTech," or "Measurements using everydaY TECHnologies"—includes the determination of the impact of students' smartphones on their learning of physics concepts, attitudes regarding their laboratory experience and use of the devices outside of class.

The data sources used to determine these impacts include the following:

- Test of Understanding Graphs – Kinematics (TUG-K);
- Colorado Learning Attitudes about Science Survey (CLASS);
- Computer Anxiety Rating Scale (CARS);
- Pre- and post-semester student surveys; and
- Video data collected in the QERL.

The QERL is the NC State Physics Department our Qualitative Education Research Lab. Data collected there yield qualitative information about behavior and interactions in the laboratory and quantitative data concerning temporal shifts in activities. The latter was made

possible using our newly developed Video Observation Tool (VOT). Anecdotal observations of TA behavior confirmed the sensitivity of the VOT.

Results from the lab equipment survey, and the TUG-K showed no statistically significant differences in the MyTech and control sections. A larger sample size might reduce statistical uncertainty, but the scope of the present study did not allow for any expansion. The VOT protocol, on the other hand, identified several activities in which students in the MyTech and control sections spent time differently in a statistically significant way. Furthermore, results from the CLASS indicate that students in the MyTech sections responded more expert-like in the category of "real world connections." Finally, pre- and post-semester surveys of technological anxiety and usage revealed that students in the control section leave their lab course with slightly more negative views of computers and students in the MyTech sections similarly exit with slightly less positive views of smartphones. A few students, however, reported having used the data collection app outside of class.

Four project objectives identified at the start of the study include: (1) creation of a new app, (2) development of a suite of labs, (3) determination of the learning benefits of the labs, and (4) determination of the attitudinal benefits of the labs. Two other outcomes emerged during the course of the study. These are: (1) construction of a software tool for educational researchers to aid in coding video data, and (2) determination of the feasibility of using the MyTech curriculum in a series of distance labs. Over the course of the MyTech study, all of these objectives were successfully accomplished.

The Educational Impact of Smartphone Implementation on
Introductory Mechanics Laboratory Classes

by
Colleen Burke Lanz

A dissertation submitted to the Graduate Faculty of
North Carolina State University
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Robert Beichner Committee Co-Chair	M.A. Paesler Committee Co-Chair
Robert Riehn	Margaret Blanchard

DEDICATION

To Preston, whose encouragement made this project possible.

BIOGRAPHY

Colleen Lanz was born in Buffalo, NY on July 19, 1986. Throughout her grade school years, she learned the importance of exceptional educators. In addition to her formal scholastic experiences, she encountered dynamic instructional techniques outside the classroom while engaging in construction projects with her father, movie discussions with her mother, and – perhaps most influentially – weekly piano lessons with her grandmother.

A strong interest in pursuing education led her to begin her college career as an education major, concentrating in Physics. During her time at Canisius College, she became equally interested in Mathematics and eventually graduated with a dual degree in both Mathematics and Physics. Her passion for both subjects caused her to struggle with which graduate degree to seek out. A couple of years later, she earned a Master's degree in Mathematics from Virginia Polytechnic Institute and went on to become a graduate student at North Carolina State University.

During her time there, she realized that she often put her teaching duties ahead of her own research and thus recognized her strong desire to engage in Physics Education Research. After joining the group, she immediately took advantage of an opportunity to study a combination of three of her favorite topics: physics, education and emerging technologies. She hopes that you will find her research as compelling as she does.

ACKNOWLEDGMENTS

I would like to thank Dr. Robert Beichner and Dr. M. A. Paesler from North Carolina State University for their helpful comments. This project was made possible due to support from NSF (grant number 1245832, under the Directorate for Education and Human Resources) and North Carolina State University's DELTA Idea Grant Program. In addition, Dr. Margaret Blanchard and Dr. Robert Riehn provided incredibly useful advice with regards to teaching beliefs and the study design, respectively. I would also like to thank the entire Physics Education Research Group at NCSU but especially William R. Sams for his essential suggestions at the outset of the MyTech project; Bin Xiao for his assistance with WebAssign, the QERL observation room and inter-rater reliability for teaching beliefs; and finally, Lili Cui, Kathleen Foote and Meghan Westlander for their guidance throughout the project. Furthermore, the MyTech project would not have been possible without the help of undergraduate physics education researcher Lillian Solliday for the inter-rater reliability process as well as undergraduate physics majors Mia De Los Reyes, José Medrano and Ephraim Bililign for their invaluable comments on the hybrid eTALK/MyTech lab project.

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1. Introduction

1.1. Purpose

This project seeks to improve the educational and attitudinal impact of instructional physics laboratories. The intent is to minimize some of the pedagogical barriers in place in many physics teaching labs by replacing expensive, purpose-built, educationally troublesome lab equipment with student-friendly devices that can be used to collect data: personal smartphones. Currently, students are required to use equipment that they will likely never again encounter in their career. The hope is that utilization of some of the internal sensors available in most smartphones (e.g. accelerometer, gyroscope, and camera) enables students to focus their attention more on the physics concepts at hand as opposed to the equipment.

We seek to ameliorate the current situation by (1) developing a smartphone app that sends the raw data being produced by the internal sensors to the student for analysis, (2) constructing a laboratory curriculum that encompasses the utilization of these smartphones, and (3) evaluating the learning benefits and (4) attitudinal benefits of the app and the curriculum.

1.2. Justification

There are a number of clear factors that motivate the implementation of smartphones into the classroom. The primary incentive is to avoid the teaching and financial obstacles associated with current popular “black-box” equipment. As a lead teaching assistant (TA) for a variety of introductory physics labs, I often witnessed students grappling with the current set of equipment, leading me to believe that the current equipment contributed to students' pedagogical hurdles. They first must learn how to use the equipment before they can begin to focus on the physics concept at hand. Then, quite often, students move on to using other equipment in subsequent experiments and the knowledge they gained in order to familiarize themselves with the prior lab's equipment is wasted. Even equipment and software that is used throughout an entire semester is generally forgotten once the students have passed the course since they normally never encounter it again.

By allowing students to use their own personal electronic devices, we hope to eliminate this steep learning curve. It has been shown that college-age students more frequently use their smartphones than in prior years (Ball State University, 2013). This built-in familiarity will hopefully allow them to bridge a learning gap involved with black-box devices in the lab. Additionally, we believe this will facilitate students' ability to connect what they learn in the classroom to their life outside the classroom and laboratory. With these sensors available all the time, the hope is that students will relish the opportunity to "take data" in the real world.

In addition to these pedagogical benefits that could potentially assist the majority of students in the classroom, it is possible to bridge a gender and ethnographic gap that has existed in physics for a long time. Many recent studies have demonstrated that women use their smartphones more than ever before (Mayer-Smith, Pedretti, & Woodrow, 2000; Women in CE, 2010), and they prefer electronic gifts over jewelry (Holland, 2010). In addition, the percentage of females that own smartphones rose from 37% in 2010 to 58% in 2013 ("Infographic shows more women own smartphones than men," 2014).

While minimizing teaching obstacles is the primary goal, reducing financial obstacles is a close second. Many small colleges find physics laboratories prohibitively expensive because of costly equipment requirements.

If we instead take advantage of the potential for data collection with students' personal smartphones, we could greatly diminish the total cost of the NCSU mechanics lab— as they are currently set up – as it would utilize less expensive equipment. Furthermore, since students provide the data-collection equipment, this cost to the institution is nullified completely.

1.3. Research Questions and Hypotheses

Throughout the study, we planned to investigate the added value (if any) of MyTech instruction. More specifically, we want to address the following:

Is there a gain in physics knowledge versus the control?

We will address in what ways the development of their collaborative learning skills and analytical skills changes and whether they gain a deeper understanding of the role of experimentation in their understanding of physics.

How do students' attitudes about laboratory experience change over time and versus the control?

The plan is to survey the students to determine how their affective and cognitive predisposition toward science evolves and whether their self-confidence in the laboratory improves.

Will students use the devices outside of the physics lab?

It is important to measure the enhanced awareness of everyday physics applications and whether or not there is an increased daily use of the sensors on the personal devices.

How will the implementation of these electronic devices affect female physics students' attitudes toward and performance in the class versus the control?

Research ("Infographic shows more women own smartphones than men", 2010; Gara, 2014) suggests that women are becoming increasingly more comfortable using their smartphones. The hope is exploiting familiar technologies will possible attract more women to STEM fields. Thus, we sought to analyze improvements made by these females, both with regard to attitude and performance.

2. Background

2.1. Popularity of Smartphones

One main concern from the outset of the project was whether smartphones were available to a sufficient fraction of students. A survey of 177 engineering majors taking introductory physics lab courses in November 2012 showed 92% of students own either a smartphone or an iPod Touch (which has capabilities similar to that of a smartphone). It is clear that smartphones are, if anything, only increasing in popularity.

In fact, a large number of universities have already introduced smartphones into their lab curriculum. In response, *The Physics Teacher* has devoted a monthly column to the topic and calls it “iPhysics Labs,” which will be discussed in greater detail later. Unfortunately, very little research has examined the impact that this increasingly adopted technological tool has had on students.

2.2. A Brief History of Physics Labs

Educators design instructional laboratories with the goal of improving student learning gains (Arons, 1990; Beichner, n.d.; Beichner, 1996; Brasell, 1987; Finkelstein, 2005; Laws, 1999a; Meltzer, 2002; Redish, 2002). Nearly every instructional undergraduate physics lab employs a computer and specialized instructional software. In order to predict where the future of instructional labs might lead us, let us first explore their origins.

The first “student participation laboratory” was created in 1825 by Amos Eaton, founder of Rensselaer Polytechnic Institute (Menzie, 1932). Over the course of the next 100 years, physics labs went through a series of evolutions, including the creation of the “Harvard Forty” in 1886 (Menzie, 1932), the creation of the first laboratory text in 1903 at Case Western (Miller, 1932), and the creation of the famous *First Course In Laboratory Physics* text from Millikan, Gale and Bishop in 1914.

The next series of significant educational breakthroughs occurred during the 1950s as the Space Race spurned a renewed interest in science. During this time, we saw the Physical Science Study Committee’s new text that required students to reduce their focus on platitudinous texts and instead approach problem-solving like a physicist (MIT Institute

Archives and Special Collections, 2012). Similarly, in the 1960s, the Harvard Project Physics (later renamed "Project Physics Course") included films and laboratory equipment (Collection of Historical Scientific Instruments: Harvard University, n.d.).

2.2.1. The Introduction of Computers into the Physics Lab

The 1970s heralded in the computer age and programming classes became increasingly popular. As a result, physics instructors began including labs that would bolster their coding and numerical analysis skills. For example, at Drexel in 1970-1971, the administrators delayed the regular physics curriculum by a quarter of a year so as to allow time to include a programming course that helped students analyze their recorded data.

But computers could also be used for data collection. During the 1980s, motion detectors that connected to the Apple IIe game port became popular. With the ability to collect position and velocity data, students could see first-hand how position-time and speed-time graphs are formed. Various programs, like *Physics Lab Helpware* (Beichner, 1985), even gave them the opportunity to duplicate a set of given curves for themselves.

Throughout the 1980s and 1990s, microcomputer-based laboratories (MBLs) became more common and, contemporaneously, the field of Physics Education Research flourished. In fact, "one might argue that early work on microcomputer-based labs (MBLs) led to the more in-depth studies that characterize today's physics education research and even contributed to the lead PER has compared to education research in other disciplines" (Beichner, n.d.).

In 1987, David Sokoloff, Ronald Thornton and Priscilla Laws began developing the earliest known set of sensors and computer interfaces, similar to the sensor interfaces used in many physics labs today. At the time, it was described as a "unified platform" for data collection on Atari computers for Priscilla Laws' "Workshop Physics" courses at Dickinson College (Laws, 1999a). The Universal Laboratory Interface (ULI) box was an analog-to-digital converter that allowed for data collection from numerous sensors. The box was built from designs by Bob Tinker at the Technical Education Research Center in Cambridge, Massachusetts. For the first time, students could take advantage of the capabilities of the interface and its corresponding software:

> "[the software] allows the students to display graphs of any measured variables against any others, to fit the graphs with various mathematical functions, to read values off the curves, to integrate the curves between chosen limits, and so on. Spreadsheets (and perhaps symbol manipulators) provide the students with tools for mathematical modeling of their experimental results." (Redish, 2002)

The Workshop Physics courses were created with the intent of having students construct and verify physics laws by observations with these new technological tools. All three weekly classes are held in the laboratory classroom along these computers, and the majority of the time is spent on the computers. The primary goal of the Workshop Physics courses are to shift the focus from the "plug-and-chug" problem-solving methods to a more constructive approach grounded in the experimental nature of physics which more closely resembles "development of enough knowledge in an area of science to allow intelligent study and observation to lead to subsequent learning without formal instruction" (Arons, 1990). Even the quasi-traditional end-of-chapter problems are context-rich, so as to require the use of the sensors and computer software in developing solutions.

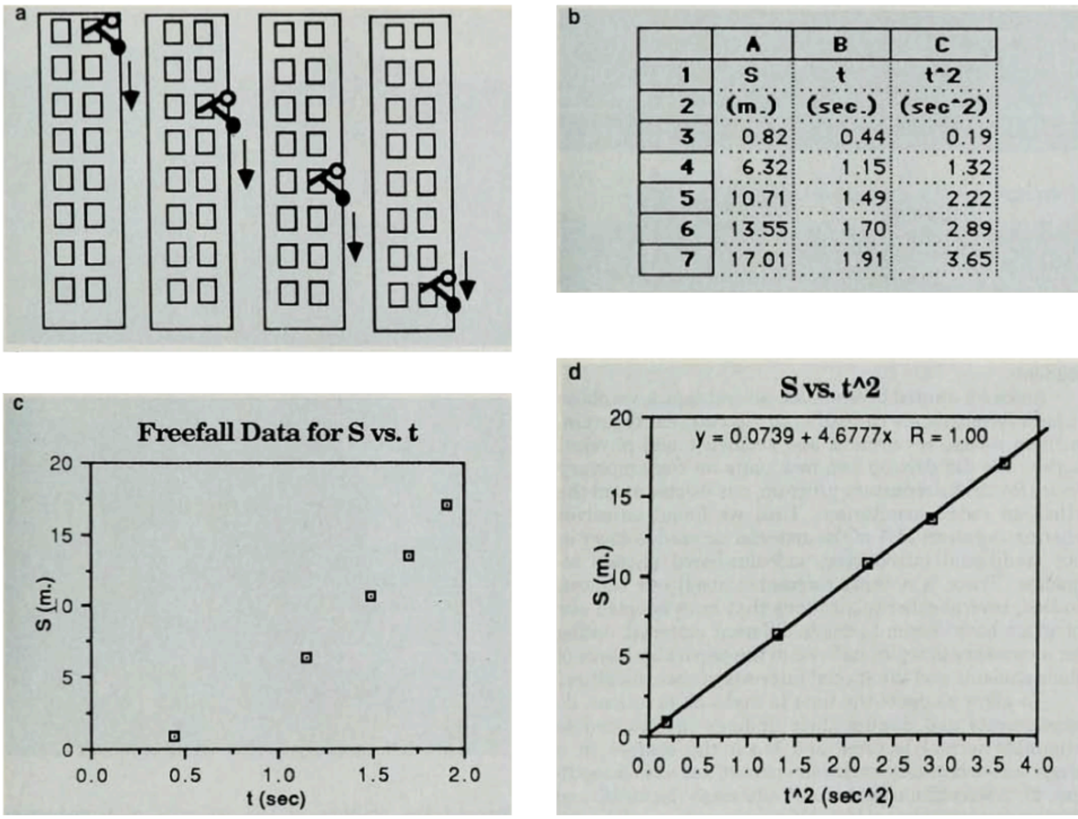


Figure 1 Students in Priscilla Laws' Workshop Physics courses were using spreadsheet and graphing software as far back as 1991 to establish physics laws.

Heather Brasell (1987) verified the importance of the *real-time* graphical displays like those used in Workshop Physics. In her study, high school physics students completed a kinematics activity using one of three treatments. The first treatment employed the use of sonic-ranger micro-computer based laboratories (MBLs) to display the dynamic creation of distance versus time and velocity versus time graphs. The second treatment simply delayed the creation of these graphs for 20-30 seconds. Finally, students in the third treatment worked on a pencil-and-paper activity that did not require a computer but asked students to predict and reproduce the MBL activities. The results of pre- and post-testing have been reproduced in the figure below. Her data suggest that "dynamic display of graphs as the data are collected is likely to help focus attention selectively on one feature at a time."

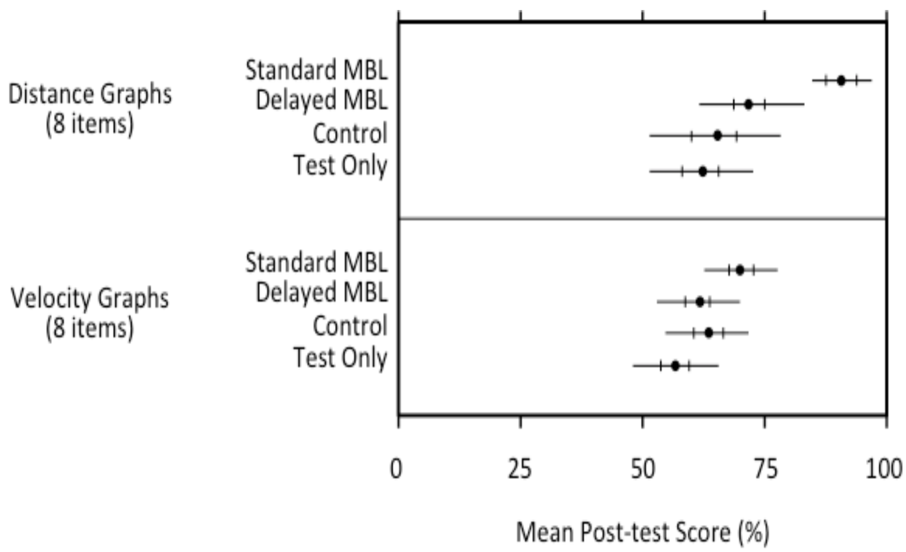


Figure 2 Heather Brasell's study demonstrated the importance of real-time graphs for Microcomputer Based Laboratories.

This method of teaching students physics was proven successful by J. Redish and E. Saul (1997). To assess the impact of this method, researchers use a normalized gain. This allows one to take effectively normalize students shifts in skill sets based on their incoming scores. The normalized gain, g, is defined as the "absolute gain divided by the maximum possible gain" (Meltzer, 2002):

$$g = \frac{\text{post-test score} - \text{pre-test score}}{\text{maximum possible pre-test score} - \text{pre-test score}}.$$

The peak on the far right of the normalized gain scale comes from Priscilla Laws' Workshop Physics Course.

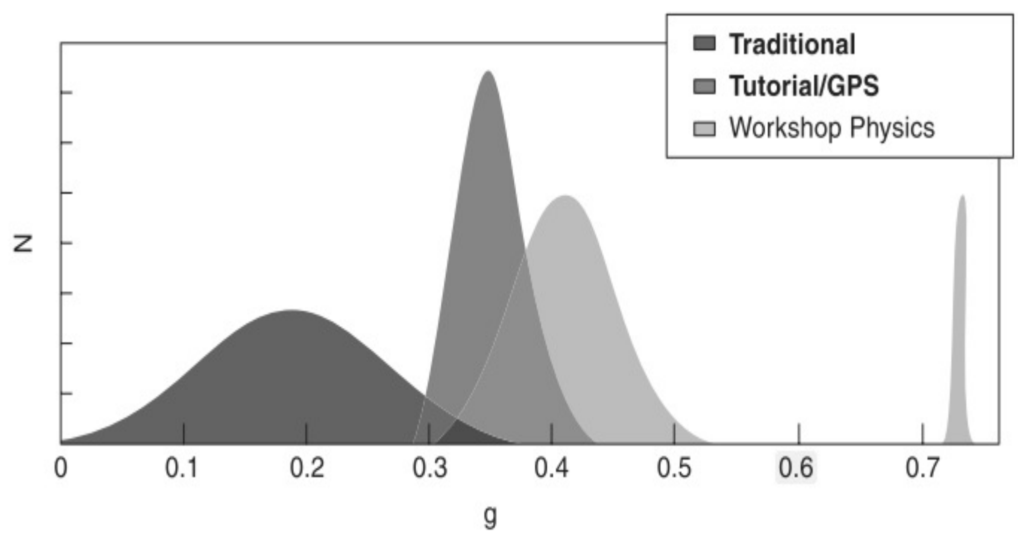


Figure 3 Distribution of normalized gain, g, for various implementations of mechanics courses. *N* represents the count of students. The lightest shade of grey represents a bimodal distribution of all Workshop Physics courses. The gains in the class taught by Priscilla Laws are represented by the right-most peak.

The 1990s ushered in the era of video analysis. For the first time, prices dropped on video cameras, VCRs and computers with capable graphics cards, therefore allowing the technology to be purchased by some schools for educational purposes. One could, for example, conduct a projectile experiment, capturing each frame of the projectile's motion and thus create a composite image containing information from all of the frames. One could then analyze the position over time.

In 1994, Dr. Robert Beichner created a program for video analysis that allowed for simultaneous viewing the video of the motion and the graph of the motion (Beichner, 1996), thereby allowing students to connect physical phenomena with the corresponding graphs on an even more intimate level.

During the early 2000s, the computer's place in the physics laboratory was solidified. Finkelstein et al. (2005) found that performance on conceptual circuit questions on the final exam of students who watched a simulated lab activity was greater than that of students who performed an actual traditional physical lab experiment. The authors also found that student performance on the write-up of a "circuit challenge" was higher overall for those that used the simulators than those in a traditional lab. This may be because simulations allow for the illustration of physical phenomena that are virtually impossible to perceive in the real world (such as current in a circuit). Ruth Chabay and Bruce Sherwood (2008) showed that students demonstrated a greater understanding of vectors and force laws after using programming simulations with VPython.

Today, a myriad of physics instructional software packages is freely available for instructors to use in their classroom or laboratory. Wolfgang Christian from Davidson College has compiled over 800 "Physlets" (short for "physics applets") that are designed to aid in students' comprehension of difficult physics concepts (Christian, n.d.). Additionally, Algodoo (Algoryx, n.d.), a free mechanical physics simulator, is less restrictive in its options and provides students with an unconstrained playground in which they can explore the effect of changing mass, frictional coefficients, shape and more on physical systems such as inclined planes, Atwood machines, spring pendula, etc. Finally, Tracker (Brown, 2015) is an extremely robust piece of video analysis software that allows users to trace the motion of a particular object frame-by-frame and output a graph of, for example, velocity versus time.

Seymour Papert (1984), a mathematician, computer scientist and professor at MIT, took the effect of computers on education to an extreme and suggested that “there won’t be any schools in the future” and that “the computer will blow up the school.” Similarly, some teachers were afraid that their jobs would be stolen by computer-aided instruction (CAI). In retrospect, this quote is of particular interest as we consider the possible impact that MOOCs (Massive Open Online Courses) and distance education classes have had on the modern-day university. We now see that technological advances have actually improved teachers’ effectiveness.

Companies like PASCO and Vernier provide instructional hardware and software and illustrate how essential computers are now in every physics laboratory.

2.2.2. Learning Companies’ Place in the Instructional Physics Laboratory

Learning companies like PASCO, Vernier, Sargent-Welch, Science Kit and Boreal Laboratories have contributed to the success of electronic data collection devices with computer interfaces in physics labs. They have embraced technology in the classroom and thus we should look to these pioneers’ ideas as we seek to include another technology—smartphones—in the physics lab.

Many of these learning companies already have data-collection probes and interfaces for students in a wide array of options. Some interfaces are stand-alone whereas others necessitate the use of a computer. Some include data analysis software. The software is robust and allows for real-time analysis from its many possible sensors. PASCO sensors and interfaces, for example, were widely adopted within the introductory physics and chemistry curricula at NCSU.

Unfortunately, the interface and its corresponding software do have some downsides. The sensors and probes manufactured by one learning company are often not compatible with those from others. In addition, the software struggles from the common issue of offering such a wide array of functionality that the interface can become overwhelming. To that end, NCSU physics students are often encouraged to open a preset configuration within the software and follow a series of “cookbook”-style instructions to complete the setup and calibration of their sensors.

Introductory mechanics labs do not require the large number of sensors available to them through these learning companies. It is not advisable to undergo a complete replacement of these devices across all curricula. These sorts of sensors may still be necessary for other chemistry and physics labs, but the only quantities collected by the software in the mechanics labs relate to velocity and acceleration. Thus, it seems natural that we should take advantage of more popular equipment such as students’ smartphones and computer webcams to collect acceleration and velocity data, respectively.

2.2.3. A Push to Include Today's Technologies into the Classroom

It is difficult for us to imagine walking into a physics lab today that did not have computers. They have become a necessity in university physics labs both for data collection and analysis. Nearly every lab in the introductory calculus-based physics class for engineering students at NCSU requires a computer to collect data through PASCO interfaces, analyze that data using Microsoft Excel, and finally, submit data and lab reports to WebAssign for grading. In addition to the technology supplied by the university, the typical undergraduate introductory physics student brings in a wide array of their own personal electronics to the lab, such as laptops, smartphones, tablets and e-book readers.

In this dissertation, I suggest that instructors should embrace this technology boom and take advantage of the students' essentially ubiquitous drive to bringing smartphones and other electronic devices into all phases of their lives by incorporating these powerful tools into teaching laboratories. By cleverly embracing these technologies, it may be possible to divert students' attention from virtual distractions like Facebook and texting to intellectually stimulating and pedagogically rewarding activities such as those available using the MyTech app.

Hoffstein and Lunetta (2004) suggested that "laboratory activities have the potential to enhance constructive social relationships as well as positive attitudes and cognitive growth." Hopefully, by embracing this new era of portable electronics, student attitudes regarding labwork may be improved upon. Students today are more technologically adept than they've ever been before, and the capabilities of their smartphones are only getting stronger with time.

2.3. Smartphone Sensors

The MyTech curriculum exploits the internal sensors found in smartphones today and allows for stream-lined analysis of the data produced by them. Most smartphones include the following internal sensors: an accelerometer (originally included to detect screen orientation), a gyroscope (for advanced motion sensing in gameplay), a camera, a magnetometer (to be used as a compass) and even a headphone jack that can serve a variety of purposes. These sensors have been put to use in both consumer and industrial electronics for the past several decades with great success.

2.3.1. The Accelerometer

An accelerometer, arguably the most useful sensor in a mechanics-based physics lab, measures a device's "proper acceleration." This is the acceleration that is experienced by an object, but it differs slightly from our usual conception acceleration (Taylor & Wheeler, 1966). For example, a *stationary* object experiences a downward pull from gravity and thus, it would read a proper acceleration of $-g$ toward the ground. This is somewhat counter-intuitive, as the object itself is stationary! A more in-depth discussion of proper acceleration will ensue in sections 2.3.2 and 4.1.1. The intent of the original inclusion of accelerometers in smartphones was to allow for determination of the device's orientation in space so as to display the screen correctly.

Accelerometers have been used in car collision notification systems (Donnelly, 1995) to determine deceleration during a crash, as well as in pedometers, video game controllers, and digital cameras to determine an object's orientation.

In addition, accelerometers have been used in several of *The Physics Teacher*'s iPhysics Lab column. In February 2012, the editors of *The Physics Teacher* started accepting articles for a monthly column that they call "iPhysics Labs". The column came as a response to a growing demand for using mobile technology ("cell phones with cameras, smart phones, tablets and the like") in the physics classroom. The column is now maintained by Jochen Kuhn and Patrik Vogt (2012a) from the Department of Physics at University of Kaiserslautern at Rhineland-Palatinate, Germany. Accelerometers have been used in conjunction with free fall labs (Vogt & Kuhn, 2012a), simple pendula (Vogt & Kuhn, 2012b), spring pendula (Kuhn & Vogt, 2012b), impulse-momentum labs (Streepey, 2013), and labs that measure radial acceleration (Vogt & Kuhn, 2013).

2.3.1.1.How the Accelerometer Works

The accelerometers that are commonly found in smartphones are capacitive acceleration sensors (CAS) etched on a silicon chip. Not unlike a mechanical force sensor usually composed of a spring and a bob (which acts as the seismic mass), a proof mass resides within the chip and is allowed to move from side to side with the phone's movement. A "proof mass" is simply a mass of a known quantity that is used in measurement devices (Vittorio, 2001). "Fingers" fixed to the proof mass slide back and forth between the teeth of a metal comb, which is anchored to the chip. The mass is positioned such that the fingers of the proof mass and the teeth of the stationary electrode comb are completely interlaced. In order to determine the movement of the proof mass, the MEMS (microelectromechanical system) accelerometer measures changes in the capacitance between the moveable fingers on the mass and the “fixed conductive electrode” of the comb’s teeth (Albarbar, Badri, Sinha & Starr, 2009). The accelerometer detects these changes in capacitance and is able to convert the information into three-dimensional acceleration data. Further discussion of this topic will ensue in section 4.1.

These raw accelerometer data are accessible through custom-made smartphone software so that acceleration in each of the three directions can easily be recorded. The maximum sampling rate on the iPhone, for example, is 100 Hz (Corona Labs, 2015). These raw data can then be made available to the user and further analyzed using software such as MATLAB or Microsoft Excel. In a physics classroom, the possibilities for labs that utilize an accelerometer are endless.

2.3.2. The Gyroscope

Gyroscopes can also be of great use to a typical physics lab student. A gyroscope, in this context, refers to an electronic device which can record rotations about each of the three axes, returning values with units of radians or degrees per unit time. Gyroscopes were initially added to smartphones in hopes of recording motion to a higher degree of accuracy than the accelerometers alone. While accelerometers are reasonably good at measuring linear acceleration, the values sometimes experience “drift,” causing velocities or distances measured using the integration of the acceleration data to be wildly inaccurate (InvenSense, 2007). Additionally, because of the equivalence of gravitational and inertial mass, accelerometers cannot differentiate between gravity and linear acceleration in the same direction. Finally, an accelerometer's data (especially when held in the somewhat unstable hand) can be rather "jittery"—a result of the slight movement of the hand. It should be noted that the jitter issue can be resolved if care is taken to attach the smartphone to equipment that causes only smooth motion in the desired direction. Gyroscopes, on the other hand, provide much cleaner data as they rely solely on the rotation of the device, and not on the linear acceleration in any direction. Most advanced gaming apps make use of both the gyroscope and the accelerometer simultaneously in order to virtually recreate the physical motion of the device. The two sensors taken in parallel provide all of the data necessary to digitize the device's motion.

2.3.2.1.How the Gyroscope Works

The other "vibrating mass" variety of gyroscope relies on calculations involving the Coriolis effect to measure rotation and remained largely a "scientific curiosity" until their inclusion in MEMS systems chips within the last fifteen years (Trusov, 2011). Currently, the majority of MEMS gyroscopes in production make use of capacitive transduction in silicon vibratory rate gyroscopes. The MEMS gyroscope uses a set of driven vibrating "wings," (IFixIt, 2015) not unlike the halteres that flying insects use to maintain motion in a desired direction.

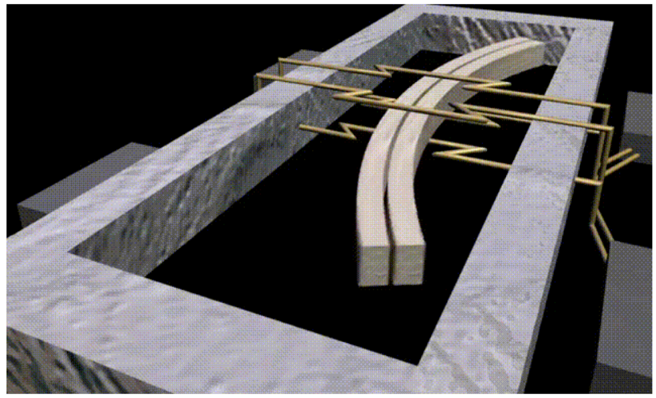


Figure 4 The halteres (left (Weiss, n.d.)) that flying insects use to maintain their desired motion in flight bear some similarity to the driven vibrating "wings" in a MEMS gyroscope (right (TaoistFlyer, 2012)).

When the wings of the MEMS proof mass are dipped or lifted (that is, rotated along the axis parallel to their "wingspan"), the wings put pressure on a piezoelectric device, which then causes a change in capacitance (Esfandyari, De Nuccio, & Xu, 2010) and is translated into a useful value representing the rotation of the device in radians or degrees per unit time (R/C 101, 2012). Suppose the driving force on the proof mass is $F(t) = F_0 \cos(\omega_d t)$ (which effectively moves the mass with some velocity $\vec{v}$) while it is subjected to a constant angular velocity (Ω) (Dong & Xiong, 2009). Then a Coriolis force is created of the form $\overrightarrow{F_C} = -2m\vec{\Omega}\times\vec{v}$ where $\vec{v}$ is the velocity of the particle in the system. This force can then be measured by the piezoelectric system.

2.3.3. Other Sensors

Smartphones also contain other sensors such as a camera, a magnetometer, a compass, a GPS locator, and even most recently, a barometer (to measure elevation changes).

Some of these sensors were used in various iPhysics labs. The camera was used for a diffraction experiment (Kuhn & Vogt, 2012c) and as a digital spectroscope (Sitar, 2012). The magnetometer was used to determine the linear relationship between the strength of a magnetic field and the number of turns of wire that produce it (Silva, 2012). The microphone was used to determine the time between bouncing balls (as a determination of *g*) (Schwarz, Vogt, & Kuhn, 2013) and in conjunction with a Fast-Fourier Transform app that allowed students to visualize the FFT spectrum for various sources of sound (Kuhn & Vogt, 2013a) In addition, some researchers took full advantage of the headphone jack as a means of connecting an oscilloscope (that read the voltage over the resistor in an RLC circuit) (Forinash & Wisman, 2012a) and a thermistor (digital thermometer) (Forinash & Wisman, 2012b). Finally, the GPS was used to sufficiently produce a graph of velocity versus time for a longboarder down a track (Gabriel & Backhaus, 2013).

These sensors were not used in the MyTech project, though and thus will not be discussed in greater detail here.

2.4. Women's Role in Technology

As mentioned in section 1.3, gender plays an important role when discussing the differences in how various students approach technological devices. In the past several years, electronic devices have trended towards becoming more social and as they do, women, on average, have become more attracted to the technology and therefore have become more familiar with it (Holland, 2013; "Infographic shows more women own smartphones than men," n.d.; Gara, 2014) . By employing this newfound interest, the hope is that female students will feel more comfortable with their physics labs and possibly improve their performance in the class as a result.

2.4.1. Females are Being Increasingly Drawn to Technology

Until recently, research has shown that men have a firmer grasp on technology than women do, on average. This has been backed by research which suggests that, while nearly everyone (regardless of gender) experiences some computer anxiety, girls and women suffer much more than boys or men (Cooper & Weaver, 2003, p. 13). These data were obtained from numerous validated surveys for computer anxiety (Cohen & Waugh, 1989; Heinssen, Glass & Knight, 1987; Mehlenbacher, Miller, Covington, Larsen, 2000). Females demonstrated a predilection toward different software features. Female students generally did not enjoy having their eye-hand coordination tested, and preferred much more that the software were more of a streamlined learning tool that provided direct and immediate feedback (Cooper & Weaver, 2003, p. 16).

In the past, females have also demonstrated a lack of confidence in using software, even when their ability level matched that of more confident males. Specifically, in 2000, survey results were released that stated the following:

> "when asked about how [female students] *felt about* their level of computer skills, women indicated far less feelings of competence (mean = 7.96 [out of 31]) than their male counterparts (mean = 11.54) – this difference occurring despite the fact that their computer skills and experience were not objectively different" (Cooper & Weaver, 2003, p. 28).

Furthermore, this increased level of anxiety can play a role on their performance level, especially if other people are present during the testing of their abilities. In a social experiment where a completely unbiased observer sat on the other side of a room while students' technological abilities were tested, females ended up performing less well than boys since the girls were prone to higher anxiety (Light, Littleton, Bale, Joiner & Messer, 2000). In fact, Cooper and Weaver (2003), authors of the book *Gender and Computing: Understanding the Digital Divide*, claim that "although they can cope with their expectation of failure while performing alone, they cannot overcome their burden in the presence of others. Anxiety and stress overwhelm them and interfere with their success" (p. 60).

In yet another social experiment performed in 1997, students were asked to work on a piece of software that required them to solve an anagram puzzle. Half of the computers had a version of a program that contained a purposeful glitch that produced a cryptic error message. Only 6% of the boys attributed this error to their lack of ability while 19% of girls believed that they were to blame for the error. The students were then asked if the problem could have been solved by trying a little harder (because they felt they could not personally solve the problem). 50% of the boys responded affirmatively, while only 31% of girls agreed (Nelson & Cooper, 1997).

Similar sentiments were identified in Priscilla Laws' revolutionary Workshop Physics course (discussed first in section 2.2.1), which replaced traditional lectures with hands-on collaborative teamwork using a series of sensors and analysis software. Female junior and senior pre-med students found the new course design unappealing and were generally more negative about their experiences than the male students (Laws, 1999b). In the study, 15 female former Workshop Physics students were interviewed to collect their thoughts on the course. While 13 of the 15 claimed that their attitudes regarding computers improved, 6 of the 15 indicated a decrease in positive attitudes after the course, 6 of the 15 indicated a positive shift and the other 3 remained unchanged. The authors of the study suspect that the majority of the problems originated within the group dynamics – whether they were composed of all of the same gender or mixed:

> "Women complained of domineering partners, clashes in temperament, being subjected to ridicule, fears that their partners didn't respect them, and feelings that their partners understood far more than they" (Laws, 1999b).

It is clear, therefore, that women have had a long history of diminished confidence in the field of computing and when this anxiety is coupled with a necessity for computers in physics laboratories, the results can be catastrophic to females in the field.

2.4.2. A New Trend in Female Computing

More recently, several reports have come out stating the ways in which females and males use mobile technology differently. In June 2012, a survey reported that women use smartphones in a different way than men do. Specifically, women check email more than men do *exclusively* on their smart-devices (57.3% to 44%), peruse Facebook and other social networking sites solely on their smart-devices more (48% to 36%) and use search engines on their mobile devices more than their male counterparts (50.9% to 39.4%) (Womenology, n.d.). Research from December 2012 suggests that, among college-aged smartphone owners, women more "obsessively" check their email than men (85% to 63%), often before they even get out of bed in the morning (Bennett, 2012).

Consistent with the results above, according to a J. D. Power survey from the second half of 2012, women were 21% more likely to download a social networking app (“Smartphone SocNet App Consumption 29% Higher for Women than Men”, 2013). We should qualify these survey results (as well as the results in the previously mentioned studies) by stating that they are dated, and the gender-mobile device landscape may have since changed. Clearly, women have an electronic presence unlike anything we’ve ever had before. Women welcome in the era of personal computing with open arms, and our newfound comfort level may allow us to feel more at ease in a physics laboratory that exploits personal technological tools.

3. Motivation

As the natural science that involves the study of matter and its motion through space and time, physics has the potential of providing learning opportunities in laboratory settings. Indeed, along with conventional reading and lecture course components, elementary physics curricula generally include laboratory periods. These periods, where students observe and measure objects as they move through space and time, have thus come to play a critical role in traditional physics pedagogy.

We must, however, not lose sight of the importance of the pedagogy in the lab. Millikan and Gale (1913) noted that while such a course is

> generally recognized as an indispensible part of any adequate course in elementary physics, it is nevertheless a lamentable fact that there are still some schools in which it is not attempted at all, while there are others in which, despite the most expensive equipment, the laboratory fails, on the whole, either to interest or instruct.

The same criticism holds true today in many traditional instructional physics labs.

The interface that the vast majority of students encounter when they first enter the lab room can present a pedagogical obstacle to some students. In the case of the labs at North Carolina State University, these interfaces allow students to collect data from a variety of sensors on the computers at their lab tables. The PASCO ScienceWorkshop 750 is the standard interface used in all of the mechanics and electricity and magnetism labs at NCSU.

In order to collect and analyze data from PASCO's set of sensors, students use the accompanying software, DataStudio. Like the PASCO ScienceWorkshop 750, DataStudio has been recently discontinued and replaced with PASCO Capstone. We will not be discussing Capstone in this paper, as it not yet the standard at NCSU.

In addition, the cost of these pieces of equipment is not negligible. And in the last 15 years, NCSU has experienced over a 15% increase in enrollment. To keep up with the student influx, the institutional cost of the equipment required to fill these physics labs also increases. These rising costs can place the future of physics labs at risk.

Currently, the NCSU Physics Department dedicates two lab rooms in the Spring semester and one lab room in the Fall to mechanics labs. Each room is composed of eight lab stations (with three students at each station). The cost of the traditional required hardware and software reduces to almost nothing with the implementation of the MyTech curriculum. The implementation of strictly smartphones in the labs does not affect the cost of the lab room or TA employment in any way.

Departments that are considering switching to a smartphone-enabled physics lab might be further encouraged to do so once they discover how popular smartphones are among undergraduate students. A recent Internet Project Survey by the Pew Research Center reveals that 83% of American adults own a smartphone.

Furthermore, another strong case for the implementation of smartphones in the physics labs was to alleviate technological anxiety (as students' personal devices might be more familiar than the lab computers), which can result in poor performance. As discussed in section 2.4, this phenomenon is present in both genders but is particularly strong in female students.

Finally, it is necessary to address the motivation for aspects of the smartphone lab curriculum that differ from the replacement of the traditional lab equipment. Currently, the traditional lab curriculum is composed of primarily "cookbook"-style labs, where students are strongly guided through a series of thorough instructions. Let us consider one example of the strong guidance provided. In lab 6 ("Impulse, Momentum and Energy") is conceptually equivalent for the smartphone and control sections. In both labs, a cart on an inclined track collides with a spring at the bottom of the track. Students examine the motion of the cart just before and just after the collision. Both sections use sensors to measure the force experienced by the cart during the collision and the velocities just before and just after the collision. They then use these measurements to verify the Momentum-Impulse Principle:

$$\vec{I} = \int_{t_i}^{t_f} \vec{F}_{net} dt = \vec{p}_f - \vec{p}_i.$$

In the smartphone section, however, strides were made to encourage independence in the students.

We suspected we could take advantage of students' familiarity with their own personal devices to promote greater autonomy in experimental methods. In addition, we wanted to be sure that we were not effectively replacing one "black box" with another, and thus wanted to increase the transparency of the devices. As such, students were provided with lab manuals that steered away from the "cookbook" style. In place of the detailed instructions, students were asked questions about their data collection and analysis. It was believed that this change was necessary in order to determine, at its core, how students used the apps without guided instruction and whether or not students were capable of troubleshooting software issues on their own. In short, we aimed to discover the impacts of swapping out the traditional equipment with smartphones as well as taking advantage of the ease of use of the smartphones to increase the autonomy of lab students.

Consider the instructions for lab 6 in the MyTech and control sections as a point of comparison. The MyTech section uses the smartphone to measure acceleration (and thus force) from the spring and Tracker to measure the velocity pre- and post-collision. The control section uses a force sensor (to measure force) and a photogate-flag apparatus (to measure the pre- and post-collision velocities). The next section considers the portions of each of the lab manuals that address experimental set up and data collection, as quoted from the lab manuals for each section (North Carolina State University, 2013):

THE CONTROL SECTION:

1. Weigh and record the mass of the cart on the worksheet.
2. Measure the width of the flag on the cart and record it on the worksheet.
3. Make sure the track is set up so that the yellow, ruled strip is facing you, and make the side of the track flush with the edge of the table.
4. Elevate the starting end of the track about 4 to 5 centimeters so that the cart can roll toward the spring bumper.
5. Move the track so that the end with the force sensor is firmly against the stop.
6. Set the photogate so that the flag clears it 1 to 2 centimeters before the cart hits the spring bumper.
7. Open the appropriate *DataStudio* file associated with this lab. The force probe will automatically be routed to analog channel A and the photogate will automatically be routed to digital channel 1.
8. Click the Experiment Setup window. [reference to figure]
9. Click the Constants tab and input your flag width.
10. Click the FORCE SENSOR in the middle of the window.
11. Then click the **Calibrate Sensors** button at the top of the Experimentl Setup window. [reference to figure]
12. Remove the force sensor from the track by loosening the bolts on the side.
13. After the Calibrate Sensors window opens go through the following steps.
    a. Hang the 500 g (4.95 N) mass from the spring (the force sensor should be in one hand with the mass hanging below the sensor).
    b. Click **Read from Sensor** and input -4.9 N in the Calibration Point 1 box. Notice the (-) sign.
    c. Remove the mass.
    d. Flip the sensor so that the spring is pointing up toward the ceiling. Steady the 500 g (4.95 N) mass on the spring.
    e. Click **Read from Sensor** and input +4.9 N in the Calibration Point 2 box. Notice the (+) sign.
    f. Click **OK** to complete the calibration process.
14. Return the force sensor to the track and tighten. Make sure the force sensor, clamp, and track all remain in place when car slides down the track and hits them. Now you are ready to begin the lab!
15. Select a starting point about 60 cm from the end of the spring bumper. Record this on the worksheet as the starting position. Note: This is the distance up the ramp from the uncompressed spring.
16. Use the meter stick to measure the vertical distance from the bottom of the tabletop to the top edge of the track at the starting position. Record this in the worksheet as the starting position height.
17. Place the cart so that the end with the flag is towards the spring bumper and the front end is lined up with the starting position.
18. Click the **START** button to start the data acquisition program and then release the cart, being careful not to push it either up or down the track. The cart should go through the photogate once on its way down and once on its way up the track for a total of two passes. Now click the **STOP** button. Practice steps 17 and 18 a few times before performing the experiment. You should be able to get the cart to return to roughly the same place each time it is released, and you should have a nice, smooth force vs. time curve. [Figure reference.]

19. Observe the position of the back end of the cart (the end that was originally at the starting position) when it temporarily stops at its maximum height. Record this on the worksheet as the stopping position.
20. Measure the vertical distance from the bottom of the tabletop to the top edge of the track at the stopping position. Record this in Data Table 1 in the worksheet.
21. Record the values of the initial and final speeds of the cart in Data Table 1. Do not delete the data set. You will need it for future analysis.
22. Repeat this procedure two more times with the exact same starting position.
23. Record the stopping position, track height, and the initial and final cart speeds each time in Data Table 1. At the end of this procedure, you should have three nice graphs of force vs. time, three sets of initial and final cart speeds, and three sets of stopping positions and track heights.
24. For each of the trials do the following.
    a. In the *DataStudio* window, click the magnifying tool [figure reference] with the dotted line around it in the top left.
    b. Use this repeatedly to zoom in on just the portion of the graph where your cart hit the spring.
    c. With just this portion of your graph highlighted, click the summation button at the top mid-right of the *DataStudio* window, and from the menu select **Area**. This will automatically calculate the area under the highlighted portion of your graph. Enter this value of the area in Data Table 2 in the worksheet.
    d. For one of the graphs calculate the area by the trapezoid method to compare with the value obtained from the computer software. Construct rectangles between 2 data points with a height equal to the average of the 2 data points. Then the area is the sum of the areas of these rectangles.

THE MYTECH SECTION

1. Weigh and record the mass of the cart.
2. Elevate the side of the track opposite the spring about 8 or 10 centimeters so that the cart can roll toward the spring bumper. Tip: Your track is two meters long, but you will only use the 60 centimeters of it closest to the spring.
3. Open Movie Maker and prepare to record video from the webcam.
4. Position the webcam so that you can fully view the 60 centimeters of the track closest to the spring.
5. Prepare the smartphone so that you can record accelerometer data as it rolls down the track. Then, place the smartphone on the cart. Tip: It is extremely important that you have the data recording rate in your app set to the fastest setting! Practice the release of the cart multiple times before you begin collecting data.
   On the axes provided below [in lab manual] sketch your prediction of what the accelerometer graph of interest will look like during the period of time that *the cart makes contact with the spring*. You may find it helpful to keep in mind that $F = ma$. What kind of force will the cart experience? Which axes acceleration are you interested in? [Figure of smartphone axes provided.]
6. Select a starting point about 60 centimeters from the spring. Record this distance.
7. Measure the vertical distance from the floor to the top edge of the track at the starting position. Record this as the starting position height.

8. Begin recording video from the webcam and accelerometer data on the smartphone. Release the cart. Tip: Be careful not to push the cart up or down the track! Push the record button for both the video and the smartphone, **wait a moment,** then release the cart.
9. Once the cart has returned back up the track, stop recording on both the computer and the smartphone. Open the webcam video in Tracker and open the accelerometer data from your smartphone in Excel.
10. In Tracker, set the appropriate clip settings and set the calibration stick distance.
11. Orient the coordinate axes, and be sure to rotate the horizontal axis so that it is parallel to the track! Then, shift + click to track the position of the cart as it moves down the track.
12. Use Tracker to determine the **maximum** height at which the cart temporarily stops after it has bounced back up the spring. (That is, you want to obtain h_4.) You can do this by navigating to the appropriate frame where the cart returns to a maximum height and clicking the "calibration stick" icon. Then choose "new calibration tape" from the pop-up menu that appears. Move your "tape" so that you can effectively measure the starting height, as shown in the screenshot below. [Figure provided.
13. Use Tracker's plots of velocity versus time to find the initial and final speeds of the cart, immediately before and after hitting the spring. (That is, you want to determine v_2 and v_3.)

The verbosity of the conventional text contrasts with the relative brevity of the MyTech text. We believe the latter better encourages student independence. Such changes were required of the smartphone labs to orient students with this new technology and familiarize them with its many capabilities. The goal of these additional questions (such as the "sketch your predicted graph" questions available in Appendix C) was to not only increase experimental laboratory skills but to also allow students to gain the confidence required to "experiment" with the app and the device outside of class.

These observations suggest that in current practice, the physics teaching laboratory experience has not been constructed to resonate with the universally accepted dictum that "learning is promoted when existing knowledge is activated as foundation for new knowledge" (Merrill, 2002). Students enter their laboratories with essentially no knowledge about the data-taking devices they use. Ironically, nearly all students walk into these laboratories in possession of a personal device with many – if not all—of the data usage capabilities they need: their smartphones. And student familiarity with their smartphones is rich and deep. The "existing knowledge" students have of their personal devices can be exploited to resonate with the universal dictum above. All one need do is to develop a laboratory curriculum that replaces awkward commercial black boxes with student smartphones. This dissertation rests on these premises.

While the Physics Education Research community has extensively studied the educational impact of digital motion detectors, MBLs, video-based labs and physics simulations, there are very few people examining the educational impact of using smartphones as data collection devices.

4. Lab Curriculum Design

The goal in the creation of these labs was to change the instructional laboratory curriculum in such a way as to allow for the integration of these new pieces of equipment (namely, the smartphones, webcams and Tracker software) while minimizing any other unnecessary modifications. This section is simply intended to introduce you to each of the labs and compare them to the traditionally taught materials. Students' responses to the lab design will be presented in section 7.3. Appendix C includes all of the MyTech curricula, including the full lab manual, selected student responses to questions unique to the MyTech lab and the WebAssign lab in which students record their responses.

The traditional lab sequence makes use of conventional measurement and experimental devices (such as pendula, meter sticks, calipers, carts and tracks) as well as the PASCO hardware interface and sensors (such as photogates and motion detectors). The

MyTech labs largely made use of the first category of equipment, with no major changes. However, the second category of equipment (the interface and the sensors) was completely replaced by smartphones, webcams and free video analysis software.

Several of the labs at the beginning of the semester require students to complete a VPython computer simulation activity. In these activities, students are typically given some portion of a VPython script that, when complete, will simulate motion of objects using concepts related to the physical portion of their laboratory experiment. For example, after the physical portion of the lab on free falling objects, students are asked to complete a portion of code that allows them to simulate dropping objects from various heights. The program then produced the "fall time" of the object. The VPython activities were included in order to provide students with programming experience at an introductory level and expose them to the types of computational activities that they might be asked to complete working in a research group.

To that end, the VPython activities were retained with no changes whatsoever in the MyTech section. As only the experimental portion of the labs were altered, students' behavior during the VPython activities were not collected nor analyzed. As a result, there will be no detailed discussion of the VPython activities in this dissertation.

4.1. Lab 1: Discovering the Smartphone's Axes/Measurements

The only lab that experienced a major transformation was the very first one. In the traditional curriculum, "Lab 1: Measurements" explores different methods of extremely basic data collection and analysis. Based on the purpose divulged in the beginning of the lab, the learning outcomes are exposed: “to learn to use various data collection and analysis methods, which will aid in future lab activities.” The primary procedural purpose of the investigation is to determine the density of a cylinder composed of an unknown material. Students weigh the cylinder using a triple-beam balance and measure the dimensions of the cylinder (length and radius/diameter) using a set of Vernier calipers. They then use the definition of density,

$$\rho = \frac{m}{V} = \frac{m}{\pi r^2 L},$$

to calculate the density of the unknown material. From a table of densities of various materials, they can determine the material from which the cylinder was made. The duration of the first lab for traditional students, based on anecdotal evidence from past teaching assistants for the course, was exceedingly small.

The first activity for the MyTech section was designed to parallel this traditional lab, and thus provided students with a basic introduction to some of the tools (for both data collection and data analysis) that they would encounter. The primary goals of this lab were to: (1) familiarize students with the smartphone’s internal sensors (the accelerometer and gyroscope, in particular), (2) prime students for extracting position versus time data from acceleration versus time data, and (3) accustom them to basic operation of the Tracker video analysis software.

4.1.1. Familiarizing Students with the Basics of a Smartphone’s Internal Sensors

This portion of the dissertation was extracted from a recent featured article published in The Physics Teacher (Countryman, 2014).

In order to understand any data set one should first understand how it is obtained.

This concern regarding the inclusion of smartphones in lab activities has arisen in response to the creation of this TPT column (Hall, 2012) as well as to a recent issue of *Physics Today* (Kowalski, 2013).

The majority of the labs featured in the iPhysicsLabs column to date make use of the internal accelerometer, common to nearly all smartphones on the market today. As was pointed out in the first article featured in the TPT column (Vogt & Kuhn, 2012a), in order to glean meaningful conclusions from their data, students should first understand how the sensor works. To this end the MyTech lab exploits a simple ball-and-spring model.

A lab dedicated to the operation of the sensor provides multiple learning opportunities that might arise from student questions, such as:

1. How can one determine the axes of the phone?
2. Why does the accelerometer read a nonzero acceleration when the smartphone is stationary?
3. (For advanced students), how is the physical motion of the device converted into a digital output?

4.1.1.1.Discovering the Smartphone's Axes

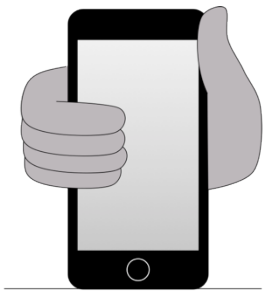


Figure 5 Students hold the phone in various orientations to determine the axes of the accelerometer.

Before using smartphones in lab, we ask students to download an app that allows them to access the raw data from their smartphone's internal sensors, such as SensorLog (Thomas, 2011) (free for the iPhone), AndroSensor (Asim, 2014) (free for Android phones) or PASCO's SPARKvue (PASCO, 2012) (available for both the iPhone and Android). To begin discovering the axes, students open the app and view the real-time accelerometer data, as shown in figure 2.

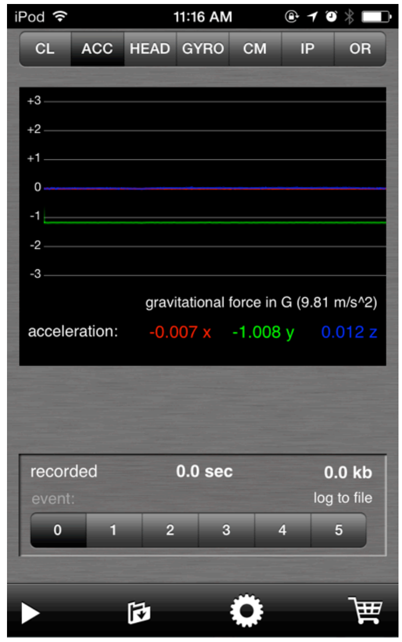


Figure 6 A screenshot from the SensorLog app when the phone is oriented as shown in the previous figure.

They explore the effect of the smartphone's orientation on these data and attempt to determine the smartphone axes. For example, they are first asked to orient the phone so that the bottom edge touches the table surface, as shown in figure 1. From the graph, they can determine the acceleration being read by the accelerometer. In this case, the iPhone reads approximately $a_x = a_z = 0$ and $a_y = -1g$. They can thus verify that the *y*-axis of the smartphone runs along the length of the phone. They can determine the *x*- and *z*-axes similarly.

4.1.1.2.The Ball and Spring Model

The fact that the smartphone accelerometer reads an acceleration of magnitude g when the phone is stationary is a common point of confusion for students and experts alike. This naturally leads into a discussion of the internal mechanics of the accelerometer and, later, Einstein's equivalence principle.

Students can be asked to picture a spring scale as a model of the accelerometer. If the scale is held upright, the weight of the mass will cause the scale to read -1g. If, however, it is instead tipped on its side, the spring will not extend, and the scale will read 0g, as illustrated in figure 3. A smartphone's accelerometer is comprised of three such spring scales, oriented along the x-, y- and z-axes.

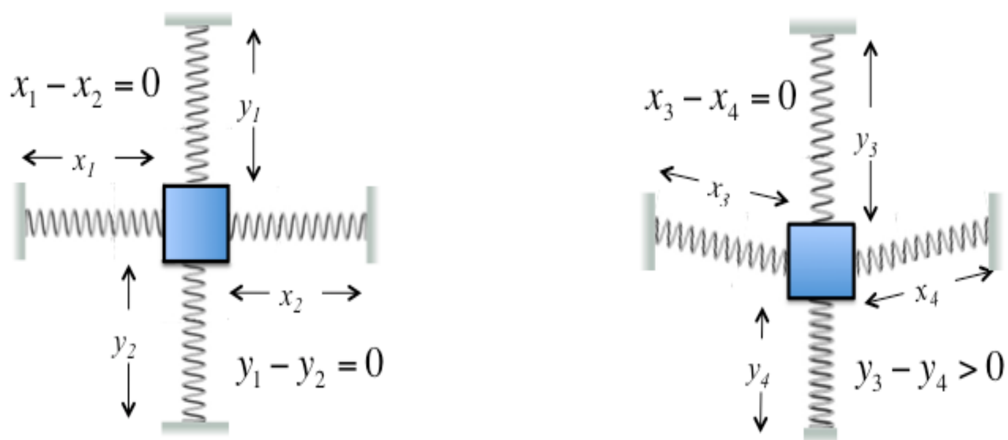


Figure 7 A simple block-and-spring schematic can be used to model the motion within the accelerometer. On the schematic on the left, the smartphone's back cover might be making contact with a flat table, so its *x-y* plane is parallel to the table's surface whereas in the picture on the right, the smartphone might be propped upright so that it's bottom edge makes contact with the table, and the proof mass moves in the –*y* direction.

In reality, the block and spring model is a simplified version of the actual accelerometer. For more advanced students, a discussion of variable capacitors and proof masses (the seismic, moveable microstructure test masses used in measurement devices) might ensue (Andrejasic & Poberaj, 2008).

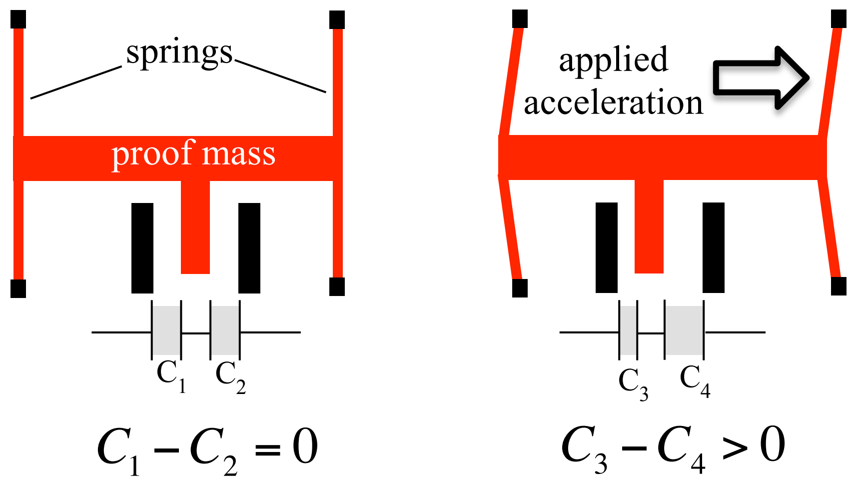


Figure 8 In the picture on the left, the proof mass inside the accelerometer chip is allowed to move freely from side to side while the black teeth are fixed to the device, changing the effective capacitance of the device. In picture on the right, the proof mass has an apparent motion to the left relative to the plates attached to the phone due to inertia.

Figure 4 demonstrates how the “block” in the simplified model is replaced with a proof mass that is bound to the fixed accelerometer chip only by spring-like silicon arms. Motion and orientation of the device are converted to a digital signal using variable capacitors, where the position of the “teeth” attached to the proof mass relative to the accelerometer housing determines the current through the device. Software converts the current output to an accelerometer reading (Hammack, Ryan & Zeich, 2012, p. 23-28).

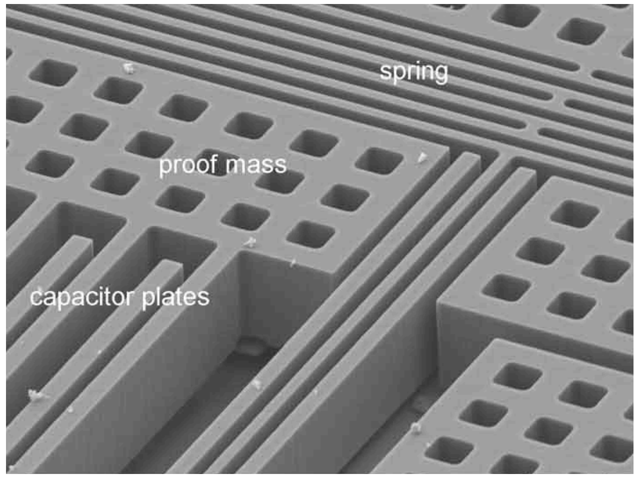
Advanced students can consider the response of a three-plate differential capacitor (two capacitors in series which share a common plate) (Hammack et al., 2012). A three-plate differential capacitor avoids the problem of the non-linear response that would occur in a two-plate capacitor with movable plates. In such a case, the capacitance (where the plate separation decreases by some small distance Δ) goes as

$$C = \frac{\epsilon A}{d - \Delta} = \frac{\epsilon A}{d\left(1 - \left(\frac{\Delta}{d}\right)\right)} \approx \frac{\epsilon A}{d}\left(1 + \frac{\Delta}{d} + \left(\frac{\Delta}{d}\right)^2\right).$$

The issue of the nonlinear dependence of Δ on C can be minimized when one considers the three-plate differential capacitor. Now, when we consider the difference in capacitance between two adjacent capacitors which share a middle plate that moves by some small distance Δ,

$$C_{\text{bottom}} - C_{\text{top}} = \frac{\epsilon A}{d-\Delta} - \frac{\epsilon A}{d+\Delta} \approx \frac{\epsilon A}{d}\left(1 + \frac{\Delta}{d} + \left(\frac{\Delta}{d}\right)^2 - 1 + \frac{\Delta}{d} - \left(\frac{\Delta}{d}\right)^2\right) = \frac{\epsilon A}{d}\left(\frac{2\Delta}{d}\right),$$

and the problem of quadratic response is diminished.



20μm

Figure 9 The microscopic structure of the silicon-based MEMS accelerometer chip (Chipworks, 2010).

4.1.1.3.Einstein's Equivalence Principle

The pedagogical key here is that the smartphone cannot differentiate a pull downward due to the Earth's gravitational force, and say, being in a rocket in outer space (where a gravitational force is nonexistent) that is thrust upward at 9.8 $^{m}/_{s^2}$, as illustrated in figure 7 below. Introductory articles to bolster one's background in the equivalence principle are widely available (Kalotas & Wybourne, 1981).

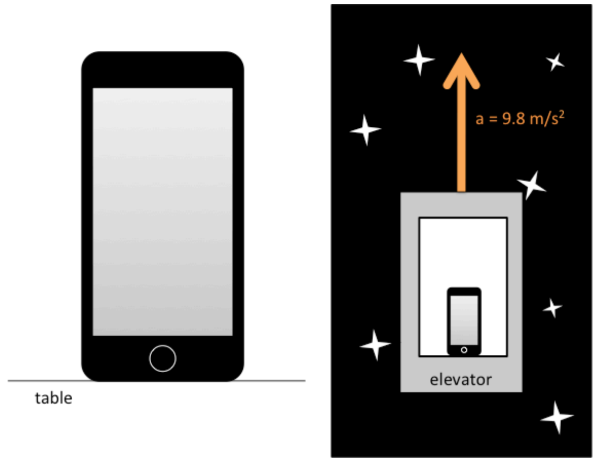


Figure 10 A smartphone that is stationary near the Earth's surface experiences the same acceleration as a smartphone in an elevator in space which moves upward at *g*.

Using pen and paper, students are then asked to predict the accelerometer output in different physical scenarios. This motivates students to consider what is happening to the "ball and spring" if, for example, the smartphone is used as the bob in a pendulum (Vogt & Kuhn, 2012b), or if the smartphone is strapped to a cart which rolls down an incline into a spring. (An accurate prediction of the latter experiment is shown in Figure 9.) This prediction will be revisited in a future lab when the students perform such an experiment.

The hope is that students will be able to obtain a better grasp on the data that they collect in these labs if they understand how it was collected. By determining the phone's internal axes and gaining a deeper understanding of how the accelerometer's motion produces a digital acceleration reading, students will be able to more easily comprehend and analyze their data. The "black boxiness" of their smartphones has thus been diminished.

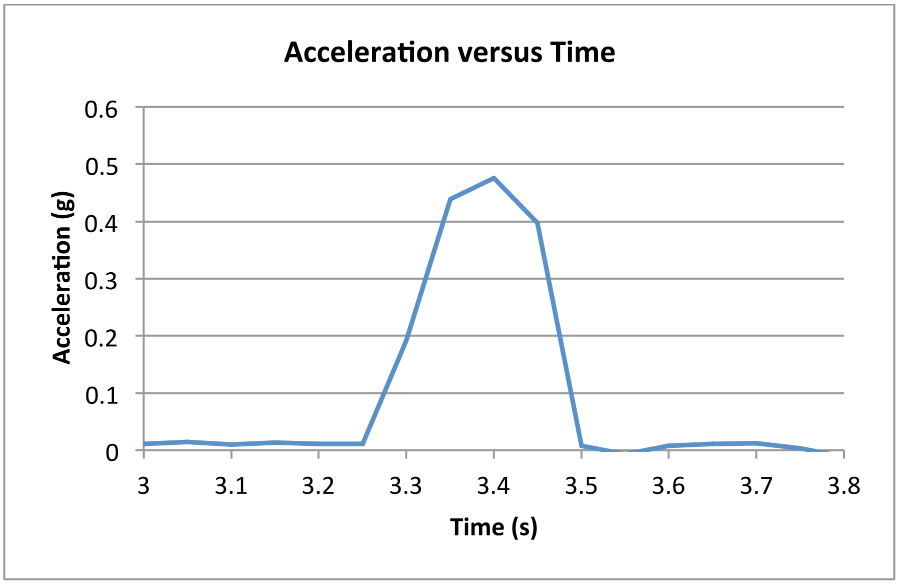


Figure 11 A recreation of students' prediction of the acceleration (along the axis in which the smartphone is moving) experienced by a smartphone attached to a cart as the smartphone-cart system rolls down an incline and collides with a spring.

This concludes the article from The Physics Teacher.

4.1.2. Extracting Position versus Time Data from Acceleration versus Time Data

One fundamental difference between the traditional labs and the MyTech labs is that, when collecting data from linear motion, the latter originally only allowed students to directly capture acceleration data. In contrast, students in the traditional labs have direct access to position data from any of the labs that require a motion detector. When the MyTech curriculum was originally conceived, this was thought to be a major pedagogical obstacle. The creation of the first lab, then, attempted to address this head on.

MyTech students are asked to recall that one can use derivatives (which correspond graphically to slopes) and integrals (which correspond graphically to areas under the curve) to switch amongst position, velocity and acceleration:

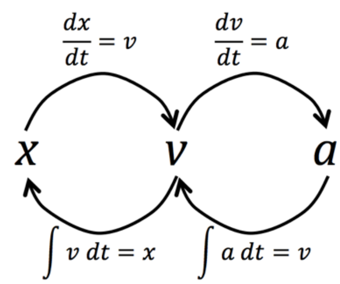


Figure 12 A diagram used to succinctly illustrate the mathematical relationships amongst position, velocity and acceleration.

Students are reminded of the following relationship among the three variables:

> Thus, since the derivative of position is velocity, the value of velocity at any given time corresponds to the slope at that time on the position versus time graph. So if your position versus time graph had a constant positive slope, this would correspond to a constant value of velocity.

This portion of the lab was created in order to encourage students to practice the process of "converting" acceleration versus time graphs to position versus time graphs. First, since generally less cognitive load is required to progress from a position graph to an acceleration graph (as compared with the inverse), students are given position versus time and velocity versus time graphs, and asked for the acceleration versus time graph. Second, they are asked to watch a video of a cart on an inclined track (Brown, n.d.). The cart bounces on a spring at the bottom of the track. Students are asked to focus on the motion of the cart during one such bounce. They are provided with the corresponding acceleration versus time graph (see below), and asked to sketch velocity and position versus time graphs for the system.

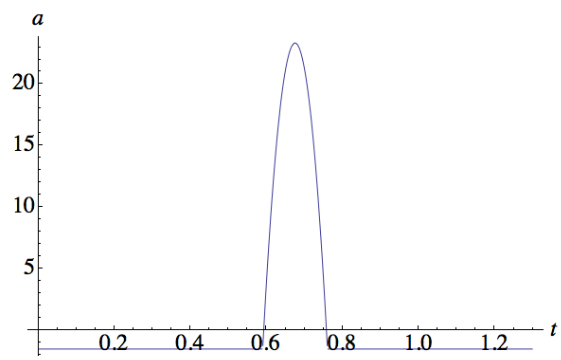


Figure 13 The acceleration versus time graph for a cart during one bounce against a spring.

In order to stress the importance of this activity, students are advised to “think about this slowly and carefully, and ask questions if you have them.” As with many plots they are asked to complete in this course, they are finally asked to take a picture of the data with their smartphone and upload them to WebAssign.

This activity later became obsolete as it became clear that position and velocity data could not accurately be obtained using the smartphone accelerometer alone (Pang & Liu, 2001). To this end, video analysis software Tracker was also utilized throughout the course in order to obtain more accurate position and velocity data.

4.1.3. Becoming Accustomed to Tracker Video Analysis Software

In the third part of their first lab, MyTech students are asked to use some of the basic analysis tools in Tracker. Tracker is free video analysis software (Brown, 2015) that allows students to import videos and track, frame by frame, the position of a moving object in the video. The instructional physics software produces various graphs and tables of interest, such as temporal graphs of position (both horizontal and vertical), velocity (both horizontal and vertical), momentum (when given the mass of the object), potential energy, etc.

They are asked to open a Tracker file that contains the motion data of the same bouncing cart video they have already seen. Upon opening this file, students see the horizontal position versus time graph. They are simply asked to choose a different quantity (the horizontal component of acceleration) for the vertical axis of the graph. The resulting acceleration versus time graph should be similar to the one provided for them in their lab manual.

They are then asked to compare their sketched graphs of velocity versus time and position versus time with the output produced by Tracker for both of these quantities and explain why the Tracker results appear the way they do.

This portion of the lab simply familiarizes students with Tracker's capabilities and how to make use of its basic features.

4.2. Lab 2: Free Fall

Traditionally, students explore the concept of free fall by dropping a soft object (such as a roll of masking tape) to the floor from six different heights, with at least 20 cm between each. They use a hand-held timer to determine the in-flight time and use the height and time data to determine an experimental value for g, the acceleration due to gravity:

$$\Delta y = v_{iy}t + \frac{1}{2}a_y t^2 = -\frac{1}{2}gt^2$$

Students in both the traditional and MyTech versions of the lab make use of the linear regression capabilities of Microsoft Excel to determine the slope ($-\frac{1}{2}g$) of the graph Δy versus t^2.

Instead of using handheld timers to record the in-flight time of an object, the MyTech students drop their smartphones (on a pillow) and use the accelerometer data to determine the in-flight time. Smartphone accelerometers can capture the in-flight time more accurately than a hand-held timer, which is susceptible to inconsistent lagging from human reaction times.

In order to facilitate interpretation of their data, MyTech students are first asked to sketch a predicted acceleration versus time graph during one free fall trial (with a labeled in-flight time). A key for this sketch is provided below with a labeled in-flight time.

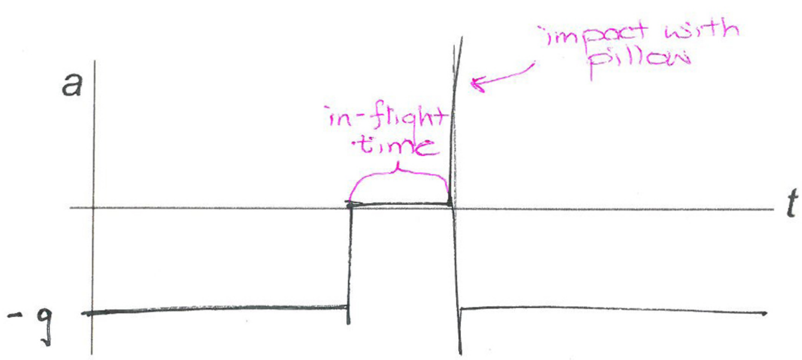


Figure 14 A correct sketch of accelerometer data during a free fall lab.

This is a pedagogically large step for the students to take from the first lab. While students in the MyTech lab become familiar with the basics of the smartphone sensors by exploring the impact of the phone's orientation on an accelerometer graph in a qualitative way, this second lab involving free fall is the first lab that requires them to record such data and analyze it in Excel. As in the first lab, students are reminded of the importance of the data collection method: "You will need to record accelerometer data often on your smartphone in this lab, so you should familiarize yourself with this process now and ask your TA if you need help."

During the first semester of MyTech labs, the instructions were left purposefully sparse as to avoid the undesirable "cookbook"-type lab, wherein students follow a series of instructions without deep consideration into the purpose of the steps. Through careful analysis of the videos from the first semester of these labs, as well as interview data from Meredith College, more detailed instructions were necessary. Thus, in the second semester of the MyTech study, the lab manual included much more detailed instructions. Because of differences in the interfaces of the Android and Apple apps, the instructions were provided in a two-column format specific to each mobile operating system, as illustrated below:

iPhone	**Android**
Open the SensorLog app. Enter accelerometer mode by tapping the "ACC" button in the upper-left. Ensure that your accelerometer has the correct settings. (a) Tap the settings button ⚙. (b) Set the recording rate to 20 Hz. (c) Make sure that the only two sensors that record data are the accelerometer and gyroscope by "turning off" CL, MAG, CM, IP, OR and STATE. (These are all other sensors that we will not need in this class.)	Open the AndroSensor app. Press the menu button on your phone and tap "settings". (a) Click "graph height" and choose "large". (b) Click "update interval" and choose "very fast". (c) Click "active sensors" and select only "accelerometer" and "gyroscope". (d) **IMPORTANT:** Click "recording interval" and choose 0.05 seconds. (e) Press the back button to return to the AndroSensor main screen.
Press the play button ▶ to begin recording.	In the upper right, tap the encircled down arrow (or swipe from left to right on the screen) to reveal the "hidden" menu. Press the record button ● to begin recording.
Press the pause button ❚❚ to stop.	Press the stop button ■ to stop.

Figure 15 A reproduction of the way that the MyTech lab manual addresses both iPhone and Android mobile operating systems.

In section 3, we had pointed out the misgivings of such detailed instructions. Unfortunately, we concluded, based on observations from the first semester of the MyTech study, that students needed this level of detail in their lab manuals. On the other hand, MyTech students more often repeat the same sorts of measurements, and thus this level of detail need not be duplicated in future labs.

As a result of these more detailed instructions, the lab manual for lab 2 is significantly longer than for the traditional labs (three pages compared to about half a page, respectively). In addition, the time required for each free fall trial is clearly significantly greater for the smartphone students than for the traditional students. Due to the extra time required as well as the increased accuracy of the data, MyTech students are required to drop the phone at just three different heights (as opposed to the six required of traditional students). We do not believe that this reduction in trials is problematic. Students attain higher accuracy with each individual trial in the MyTech sections and they still have the opportunity to run through all of the same data analysis as their cohorts in the traditional sections. We do not believe that there is much added impact of the traditional students' additional trials.

4.3. Lab 3: Uniformly Accelerated Motion

In this lab (in both the smartphone and control sections) students explore one-dimensional motion when a constant force is applied to the moving object, and analyze the data in the context of the Momentum Principle ($\Delta p = F_{net}\Delta t$) or Newton's Second Law ($F = ma$). In this case, the two labs are similar in that they involve a fan-cart system placed on a horizontal track. Students use the DataStudio software to produce velocity versus time graphs for the moving fan-cart with (1) a constant force and no initial velocity and (2) a constant force opposite to an initial velocity.

Neither the smartphone section nor the control section uses a smartphone in this lab. Instead, velocity data are collected using a motion sensor, PASCO ScienceWorkshop interface and PASCO DataStudio software in the traditional lab, whereas the MyTech lab makes use of a webcam and Tracker software.

Students in the MyTech section are provided with strong guidance in the setup of their experiment. The lab manual makes strong suggestions ("Do not hand-hold the webcam!

It is very important that the image is very steady!") to increase the quality of their experimental data. While we believe that this added detail hinders students' autonomy somewhat, we believe it is a necessary step in the procurement of quality data.

Because this is the first lab that required students to start "from scratch" with a video file they created in Tracker, the instructions provide a step-by-step procedure so they could independently obtain the desired velocity versus time graphs. This includes setting up a coordinate system on the video file, and tracking – frame by frame – the fan-cart system in the video. MyTech students are then asked to upload the resulting graphs and answer some brief conceptual questions (such as "what do you have to do to make the graph of *x* versus *t* a horizontal line?"). Students then repeat the experiment with the addition of an initial push opposite the fan's force. They then complete a series of conceptual questions identical to the traditional lab groups' questions.

4.4. Lab 4: Measuring Impulse and Momentum in One Dimension

In this lab students relate measurements involving impulse ($\vec{J}$) to measurements involving changes in momentum ($\Delta\vec{p}$), according to the following equation:

$$\vec{J} = \int_{t_i}^{t_f} \vec{F}_{net}\, dt = \vec{p}_f - \vec{p}_i \,.$$

Both labs make use of a cart on a horizontal track with a spring "bumper" at one end of the track. The cart is given an initial velocity toward the spring, and the impulse and change in momentum of the cart are measured during the spring-cart collision.

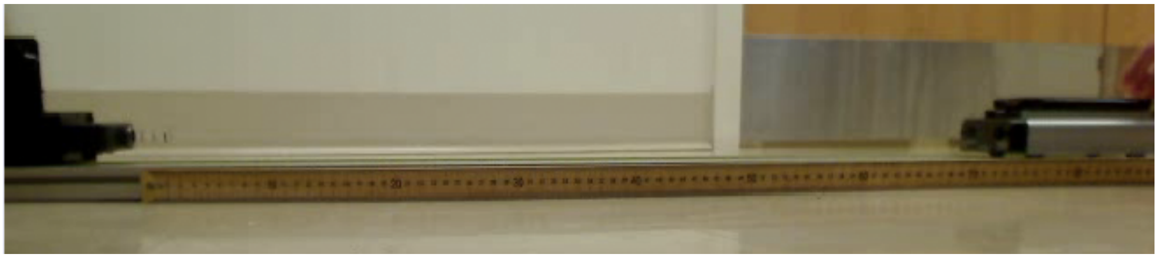


Figure 16 A screenshot of the spring-cart collision in Tracker. This image was provided in the MyTech lab manual.

In the traditional lab, two sensors are used: a motion sensor captures velocity data while a spring sensor collects force data during impact. In contrast, the MyTech students use Tracker to collect velocity data and the smartphone's accelerometer (attached to the cart) to collect force/acceleration data during impact.

As with the other MyTech labs, students are asked to sketch their predicted accelerometer output (to be verified with the smartphone) and momentum output (to be verified with Tracker). Beyond that, there are no conceptual questions asked of the MyTech students that are not asked of the traditional students.

As students are expected to have gained some familiarity with Tracker and their smartphones in previous labs, the instructions for this lab are more sparse as compared with their predecessors. Instead of detailed step-by-step Tracker instructions, a simple reminder of the necessary icons on the Tracker toolbar is provided:

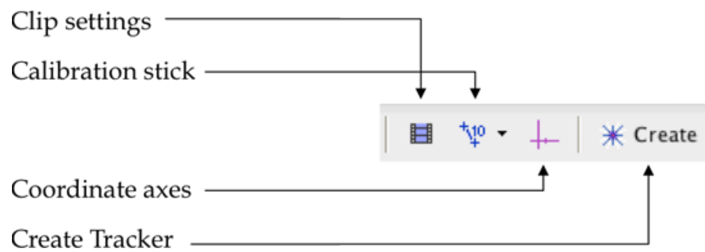


Figure 17 Tracker's menu buttons of interest to PY 206 students.

along with brief descriptions of what to do (such as “position and rotate the coordinate axes so that it lines up with the track”). In this way, instructions in the MyTech lab manual may appear as detailed and lengthy as their traditional counterpart’s early on in the semester. However, since students in the traditional section use new equipment and sensors in nearly every lab, they need extremely detailed instructions for nearly every lab.

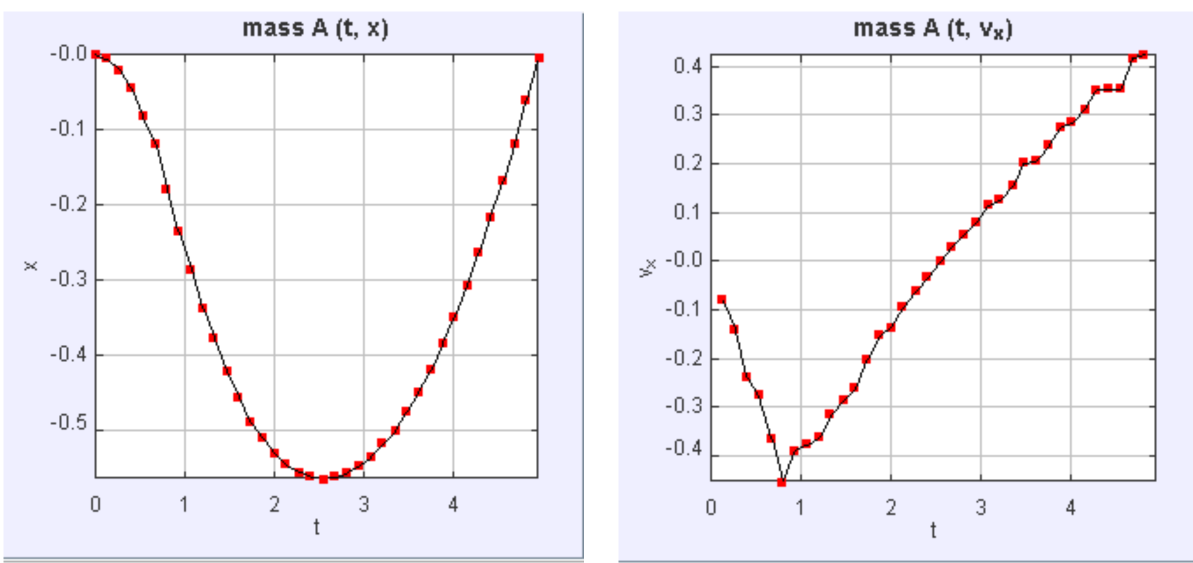


Figure 18 Student-produced Tracker graphs from the "force opposite to initial velocity" portion of the lab.

The only conceptual difference between the two labs results from calculating the area under the resulting F_x versus t curves. PASCO's DataStudio provides a tool ("Σ") that relatively easily calculates the area under the curve. Excel –as far as I can tell—has no such graphical tool and so, instead, students are simply asked to estimate the area under the curve by finding the average value of force, $F_{\text{x,avg}}$, and multiply it by the total duration of the collision, Δt.

4.5. Lab 5: Uniform Circular Motion

In both sections of this lab, students are provided with an apparatus composed of a hollow rod, a string that is threaded through the rod, and a mass and rubber stopped connected to the two ends of the string, as illustrated in the figure below:

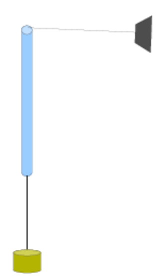


Figure 19 The Uniform Circular Motion apparatus.

The purpose of the lab is to (1) determine the mass of the rubber stopper by swinging it over one's head (as demonstrated in a YouTube video (Ozark Adventist Academy, 2010)) and measure the radius of the arc as well as the period of the swing and (2) to account for the gravitational pull on the rubber stopper and determine that the angle that the stopper makes with the ground is irrelevant to the determination of the mass.

In the MyTech and traditional sections, the first parts of the lab are identical. Students use a hand-held timer and a meter stick to determine the period of the swing and radius of the arc, respectively. Then, students can calculate the centripetal acceleration:

$$a_c = \frac{v^2}{r} = \frac{1}{r}\left(\frac{2\pi r}{T}\right)^2 = \frac{4\pi^2 r}{T^2}.$$

Equating the centripetal force on the stopper and the tension in the string, they can use linear regression to calculate the mass of the stopper, M_s from the mass of the hanger, m_h and the centripetal acceleration, a_c:

$$F_c = F_T \quad and \quad m_h g = M_s a_c.$$

In part two of the lab, students take into account the gravitational force on the stopper. To do this, they measure the angle, θ, in the figure below:

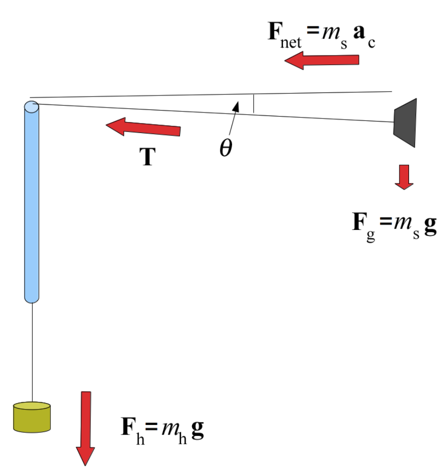


Figure 20 A more detailed schematic of the Uniform Circular Motion apparatus.

The only difference in these labs is that the traditional students use a protractor in mid-air to determine the angle, θ, while the MyTech students record a video of the swinging process with a webcam and determine θ using Tracker. The extra time spent during this process is rationalized by the increased accuracy of the measurement of the angle, θ. Students determine that taking this angle into account does not impact their calculated stopper mass. The remaining conceptual questions were asked of both the MyTech and traditional sections, with no differences between the two.

4.6. Lab 6: Impulse, Momentum and Energy

In this lab students: (1) verify the impulse-momentum theorem ($\vec{J} = \int_{t_i}^{t_f} \vec{F}_{net}\, dt = \vec{p}_f - \vec{p}_i$) by investigating the collision of a moving cart with a fixed spring and (2) use the work-energy theorem ($\Delta K = W$) to evaluate the energy losses during the collision.

As with lab 4, in the MyTech section students use the smartphone accelerometer attached to a moving cart to determine F_{net} and a webcam with Tracker software to determine Δp. In the traditional section, however, students use a different set of sensors to determine the same quantities in lab 4. As before, the students in the traditional section use a spring sensor to determine the force, but instead of using a motion detector to determine the velocity, they instead use a photogate (pictured below) to determine the velocity just before and just after collision with the spring.

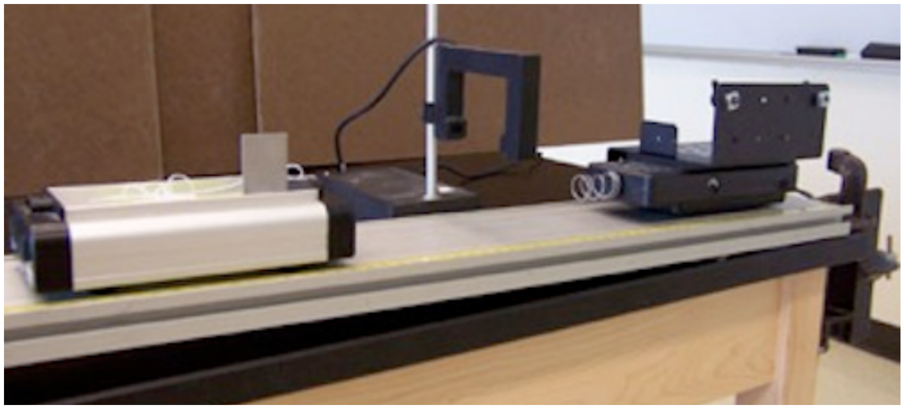


Figure 21 The traditional setup for the Impulse, Momentum and Energy lab (courtesy of the traditional PY 205 lab manual).

From a series of theoretical calculations, students determine that

$$\Delta E_{tot} = W_{NC}^{coll} + W_{NC}^{trav},$$

where $\Delta E_{tot} = U_4 - U_1$, using the notation given in the lab manual and $W_{NC}^{coll} = K_3 - K_2$. Students can thus conclude W_{NC}^{coll} and W_{NC}^{trav}. The kinetic energies, K_3 and K_2, can be ascertained using the velocity measurements, since $K = \frac{1}{2}mv^2$.

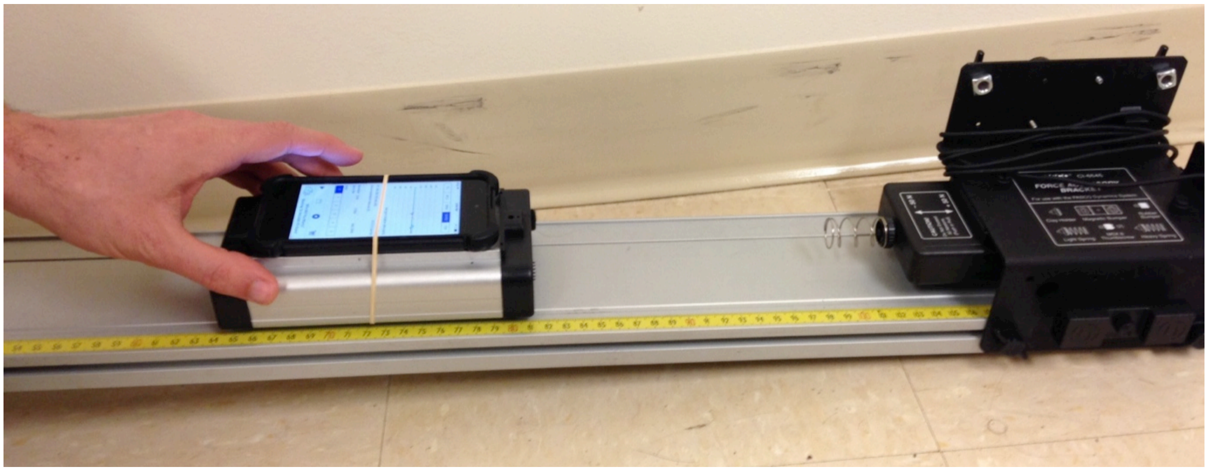


Figure 22 The MyTech setup for the Impulse, Momentum and Energy lab.

Students in the MyTech lab are asked two additional conceptual questions. In the first, they are asked to predict the resulting accelerometer graph as the cart collides with the spring. At this point, students can draw upon their knowledge of this impact from lab 4. They are then asked about the axis of interest on the smartphone itself. As before, the MyTech students do not have access to the summation button (Σ) in DataStudio. In order to determine the area under the acceleration curve, students are asked to use the trapezoidal rule, as illustrated below.

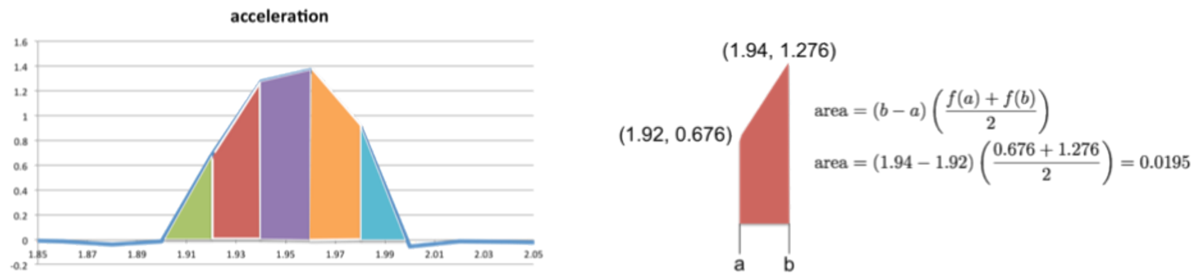


Figure 23 The MyTech lab manual provides students with a reminder of how to estimate the area under a curve.

Some readers may be concerned about the additional time required of the trapezoidal rule. However, students in the traditional lab spend more time attempting to set up the experiment because the spring sensor requires an elaborate calibration process. We can thus justify this additional time in analysis for MyTech students.

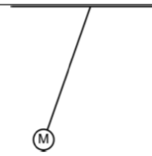
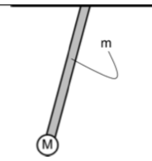
4.7. Lab 7: Simple Harmonic Motion

In this lab, both the MyTech and traditional lab students explore simple harmonic motion using spring pendula and simple pendula. Both labs require students to determine the spring constant, k, of their group's spring using Hooke's Law ($|\vec{F}_{spring}| = ks$). Students are then asked to set the spring pendula into motion, and graph the square of its period (T^2 measuring using a traditional stopwatch) against differing masses (m). They then use linear regression and the equations of simple harmonic motion in springs $\left(T = 2\pi\sqrt{\frac{m}{k}}\right)$ to determine the value of the spring constant. Similarly, students set a simple pendulum into motion and graph the square of its period (T^2, measured using a traditional stopwatch) against differing lengths (L). They then use linear regression and equations of simple harmonic motion in simple pendula $\left(T = 2\pi\sqrt{\frac{L}{g}}\right)$ to determine the acceleration due to gravity, g.

Due to the brevity of this lab, students in the MyTech section were also required to complete another portion involving physical pendula. In the initial design of the lab, a smartphone was to serve as a data collection device by replacing the "bob" at the end of a simple pendulum with a smartphone. Accelerometer data from the smartphone allowed students to more accurately determine the period of the pendulum. However, due to logistic limitations in the design of the smartphone-holding pendulum apparatus, a rod (with uniformly distributed non-negligible mass) was required to support the weight of the smartphone. This apparatus, then, no longer mimicked a simple pendulum, but instead a physical pendulum with weight distributed along the rod.

The PY 205 curriculum at NCSU does not traditionally cover physical pendula in class. Therefore, a brief discussion of physical pendula is provided in the lab manual. In theory, the period of a physical pendulum thus differs from a simple pendulum by a multiplicative factor, *F*. While this factor can be determined theoretically, we opted for greater accuracy during the lab by pre-determining this multiplicative factor. The multiplicative factor, *F*, and a table summarizing this effect (reproduced below) is provided to students in their lab manual.

Table 1 The visual and mathematical differences between simple and physical pendula.

simple pendulum		$T = 2\pi\sqrt{\frac{L}{g}}$
physical pendulum		$T = 2\pi F\sqrt{\frac{L}{g}}$

In addition, more details on physical pendula and the calculation of the multiplicative factor, F, are provided in an optional document titled "Physical Pendulum Concepts," also provided in Appendix C).

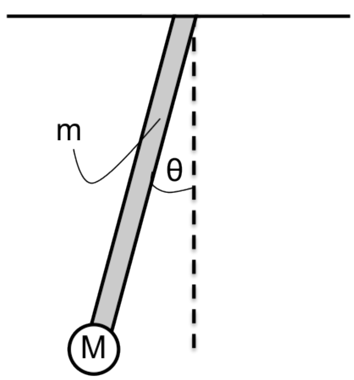


Figure 24 A schematic of a physical pendulum.

Students are urged to consider a physical pendulum, whose mass is distributed along the length of the rod, L, (where m is the mass of the rod) as well as clustered at the bottom of the pendulum (where M is the mass of the pendulum bob). The net gravitational torque on the system at an arbitrarily small angle, θ, is given by:

$$\tau = -\left(\frac{L}{2}mg + L_{cm}Mg\right)\sin\theta\,,$$

where L is the full length of the pendulum, and L_{cm} is the distance from the axle to the center of mass of the smartphone. The negative sign exists because the torque opposes the angular displacement from equilibrium.

Keeping in mind that $\tau = I\alpha = I\left(\frac{d^2\theta}{dt^2}\right)$ and that θ is small, we can now say

$$\tau = -\left(\frac{L}{2}mg + L_{cm}Mg\right)\sin\theta$$

$$I\frac{d^2\theta}{dt^2} = -\left(\frac{L}{2}mg + L_{cm}Mg\right)\sin\theta$$

$$0 = I\frac{d^2\theta}{dt^2} + \left(\frac{L}{2}mg + L_{cm}Mg\right)\sin\theta$$

$$0 \approx \frac{d^2\theta}{dt^2} + \frac{\frac{L}{2}mg + L_{cm}Mg}{I}\theta$$

$$0 \approx \frac{d^2\theta}{dt^2} + \omega^2\theta$$

where $I = \frac{1}{12}mL^2 + ML_{cm}^2$ and we can obtain an angular frequency:

$$\omega^2 = \frac{4\pi^2}{T^2} = \frac{1}{I}\left(\frac{L}{2}mg + L_{cm}Mg\right).$$

We can then solve for the period, T:

$$T^2 = \frac{4\pi^2 I}{\frac{L}{2}mg + L_{cm}Mg}$$

$$T^2 = 4\pi^2 \left(\frac{\frac{1}{12}mL^2 + ML_{cm}^2}{\frac{L}{2}mg + L_{cm}Mg} \right).$$

If we define $L_{cm} \coloneqq fL$, then

$$T^2 = \frac{4\pi^2}{Lg} \left(\frac{m\left(\frac{L^2}{12}\right) + M(fL)^2}{\frac{m}{2} + fM} \right)$$

$$T^2 = \frac{4\pi^2 L}{g} \left(\frac{\frac{m}{12} + f^2 M}{\frac{m}{2} + fM} \right)$$

$$T = 2\pi \sqrt{\frac{L}{g}} \sqrt{\frac{\frac{m}{12} + f^2 M}{\frac{m}{2} + fM}}.$$

We can define $F \coloneqq \sqrt{\frac{\frac{m}{12}+f^2 M}{\frac{m}{2}+fM}}$, so that we may write the simplified period of a physical pendulum as

$$T = 2\pi \sqrt{\frac{L}{g}} F.$$

Using the masses of the rods (without the axles at the top), you can find the values of F for rods of varying lengths:

Table 2 The corrective factor, *F*, for the physical pendula of various lengths, *L*

L (m)	*F*
0.7165	0.886
0.6170	0.872
0.5090	0.873
0.4155	0.882

Because the values of F were so close, we provided students with the average value of $F = 0.878$ in the experiment.

Students are then asked to determine the period of the pendulum by attaching their smartphones to the bottom of the physical pendulum apparatus and analyzing the recorded accelerometer data. They could thus again determine the acceleration due to gravity, g. Further discussion of this method ensues in section 7.3.7.

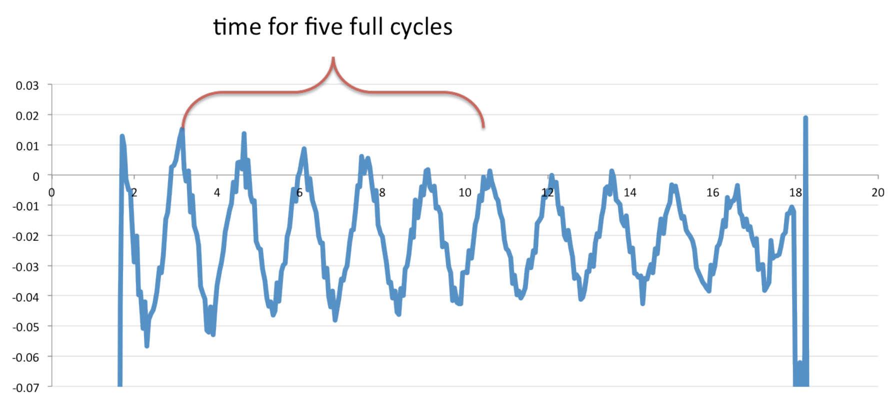


Figure 25 The *z*-axis accelerometer output from a smartphone used as a "bob" in a physical pendulum.

4.8. Lab 8: Conservation of Mechanical Energy

In this lab, students are asked to roll a marble down a curved ramp, off a table and onto the floor, as illustrated in the figure below.

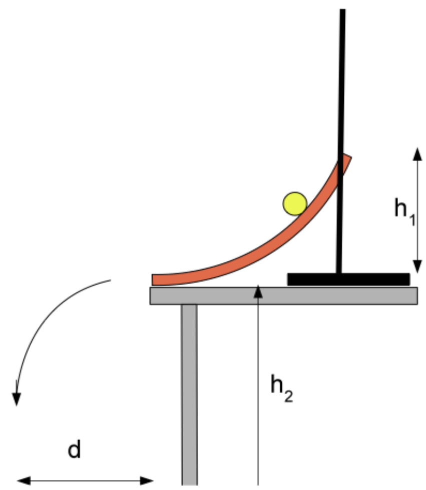


Figure 26 The setup for the conservation of energy lab.

Students in the traditional section of the lab are asked to determine the speed of the ball as it leaves the table using two different methods: (1) kinematics, treating the ball as a point mass in free fall and (2) energy, looking at conservation of the ball's energy. The learning outcome of the lab is primarily for students to realize that these sorts of trajectory problems are much more easily solved using energy equations, as opposed to the kinematics equations that they have primarily used up until this point.

In addition, students in the MyTech section are also required to (3) verify their theoretical results for the final velocity of the marble as it leaves the table using a webcam and Tracker. It was not anticipated that this portion of the procedure would be particularly time-consuming. No additional conceptual questions are required of the students in the MyTech section. The lab manuals are both less than three pages in length.

Students' comments in the Tracker portion of this lab is provided in section 7.3.8 and the lab will be discussed in greater detail at that point.

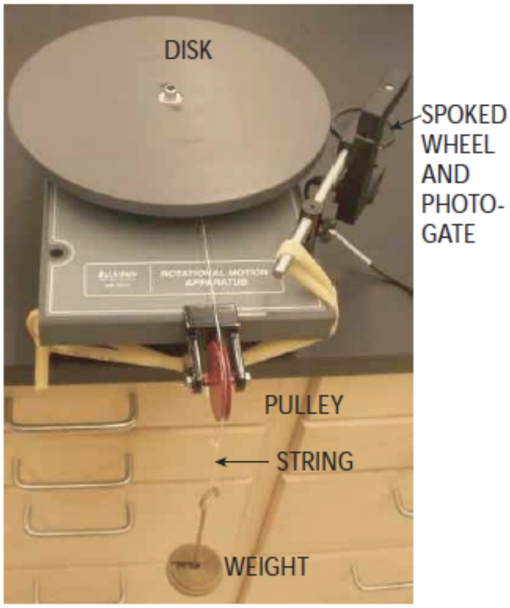
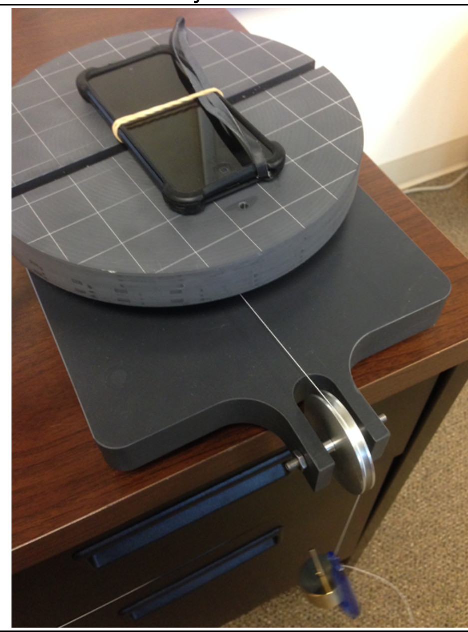
4.9. Lab 9: Angular Impulse and Angular Momentum Change

For both sections of the lab, students are to use measurements to verify that the angular impulse, $\vec{\tau}_A \Delta t$, is equivalent to the change in angular momentum, $\Delta\vec{L}$ using a large rotational apparatus (a large disk allowed to rotate like a turntable), a pulley and a set of hanging masses.

There are two primary differences in the two sections of the lab. The first involves the equipment used. The traditional lab uses a spoke wheel and photogate in contact with the disk to determine tangential velocity, v, (and thus the angular speed, ω) of the disk. The MyTech students instead strap a smartphone to the center of the rotating disk and allow it to capture gyroscopic data to determine directly the angular speed, ω, of the disk. Note that traditional lab students require an extra step ($v = \omega R$) to determine this angular speed.

The second difference between the two sections is that the MyTech section must incorporate the moment of inertia, I, for the phone in their calculation of disk-phone system. Such a calculation is only *later* required of the traditional students, who are first asked to perform the experiment using only the rotating disk and *later* asked to perform the experiment with an additional large rectangular piece on top of the turntable. Thus, this is not thought to be a major alteration to the lab as it really only changed the order in which students are asked to consider the impact on the moment of inertia for a system after the addition of a rectangular object. A comparison of the two laboratory setups is provided on the next page.

Table 3 Differences in angular momentum equipment for MyTech and Traditional curricula

Traditional Lab	MyTech Lab
	

4.10. Lab 10: Macroscopic and Microscopic Springs

This is the only lab in which the MyTech version is essentially identical to the traditional version. In this lab, students are asked to explore principles related to Young's Modulus, a concept not covered in a traditional PY 205 curriculum. It should, however, be noted that since the departmental decision to merge students in the PY 205N and PY 205M courses into a non-designated PY 205 lab, *some* students in the labs will have been exposed to the relevant material in their lectures. In short, students will investigate the spring-like properties of a straight wire, discover the "stretchiness" of a material and relate macroscopic "stretchiness" of a material to microscopic stiffness of the interatomic bonds.

This lab relied completely on simple conventional lab equipment, like strings, calipers and rulers. Since it did not make use of any of the interfaces or sensors, the integration of smartphone sensors or Tracker analysis would have been impractical and senseless. Thus, temporal analysis of this lab was used as a "control" with which we could compare the traditional and MyTech students. The results of this data will be revealed in a later section.

4.11. Lab 11: Speed Dependence of the Air Resistance Force

The last lab of the semester involved air drag. This is typically an optional topic in most PY 205 curricula at NCSU. Thus, the beginning of both sections' lab manuals includes a full theoretical discussion of air resistance, drag coefficients and terminal speed. In both lab sections, students are asked to drop a series of coffee filters of varying sizes and masses. They are asked to determine the terminal speed of the filter(s) using two different methods. The traditional section drops the filter(s) from a height exceeding one meter, and uses a stopwatch to determine the time that the filter(s) take during the last meter of their fall. (A back-of-the-envelope calculation is used to persuade students that the filters have reached terminal velocity by the time it reaches a meter above the ground.) In addition to using stopwatches, the MyTech students use a webcam and Tracker to determine the terminal velocity of the filters during the last meter of their fall.

Both the MyTech and traditional sections take six data points using the stopwatch, and the MyTech section takes an additional three data points using Tracker. The instructions for both sections are three pages in length. Again, we will discuss students' responses to this lab in section 7.3.11.

4.12. Summary

As we compare the traditional and MyTech lab curricula, it is clear that the MyTech series of labs was changed as little as possible from the traditional series so as to allow for the inclusion of students' familiar data collection devices. In some cases, MyTech students and traditional lab students had the same requirements, and the only difference between the sections was that the lab equipment had been swapped. In some of the other labs, MyTech students were asked to complete an extra portion that was not required of the traditional students. The intent of these additional questions was to make better use of the laboratory time allotted to them by getting students to learn more about the way in which their new equipment collects data. Where possible, we attempted to separate the effects of the equipment from the effects of these additional questions in the study.

5. Study Design and Research Questions

5.1. Data Collection for the Study

We recorded data from North Carolina State University PY 206 students over the course of three semesters. PY 206 is the one-credit-hour laboratory component of the first semester of a two semester course in Physics for Engineers and Scientists. The course is aimed primarily at engineering majors and utilizes mathematical methods gained in a calculus class. Each semester, two sections of PY 206 were performed in the Qualitative

Education Research Laboratory located in the physics building. (Typically, PY 206 at NCSU is run in the Maryanne Fox Teaching Laboratory Building.)

The QERL (pictured below) incorporates a one-way mirror, four ceiling cameras, and several tabletop conference microphones. It can accommodate up to 12 students and one teaching assistant. Due to size constraints, the 12 student PY 206 sections used in this study are approximately half the size of those scheduled into a traditional lab room.

Figure 27 NCSU's Qualitative Education Research Lab (QERL).

Primarily, the subjects in the study are freshman or sophomore engineering majors with some background in calculus. Students are assigned to work in four groups of three students. Groups of four or more are strongly discouraged but sometimes occurred as a result of the late arrival of one or two students.

In each semester of the study (Fall 2013, Spring 2014 and Fall 2014), the behavior and discussion of students in two sections were recorded. The same TA guided the laboratory experiments of both sections during a given semester. (These TAs differed from semester to semester). The first section utilized the MyTech curriculum and the second section utilized the traditional curriculum. The first section ran on Fridays from 10:15 AM to 12:05 PM and the second section ran subsequently (from 12:25 PM to 2:15 PM). The timing and location were maintained throughout the duration of the study.

Additionally, due to the shortage of females in the engineering courses at NCSU, we also attempted three laboratory experiments at Meredith College, which houses an all-female population. There are a number of differences between the physics course at Meredith (PHY 241, General Physics I) and the PY 206 course at NCSU. Meredith's physics course was not intended for engineering majors and was thus less mathematically rigorous. They also used slightly different lab equipment than NCSU used in their traditional labs. As a result, the MyTech labs were adapted somewhat to fit in more appropriately with their curriculum. Relocation of all of the students to the QERL would have been logistically difficult, so we recorded the actions of two groups in their traditional setting on the campus of Meredith College using two stand-alone tripod-mounted cameras with tabletop conference microphones. Furthermore, informal post-laboratory interviews were conducted with the Meredith students using a hand-held camera in order to procure immediate feedback on the labs.

5.2. Objectives of the MyTech Study

Four primary objectives of the study were identified at the outset of this project: (1) creation of a new app, (2) development of a suite of labs, (3) determination of the learning benefits of the labs, and (4) determination of the attitudinal benefits of the labs. Subsequently, outcomes emerged: (1) construction of a software tool for educational researchers to aid in coding video data and (2) determination of the feasibility of using the MyTech curriculum in a series of distance labs.

While the motivation behind several of these goals may be obvious to some, for completeness we will explicitly consider the impetus for each objective.

5.2.1. Objective 1: Creation of a New App

At the outset of the study, two pre-existing smartphone apps were deemed sufficient for the purposes of the study. Unfortunately, no single app existed for both Android and iOS mobile devices that could provide a unified interface. The two apps, SensorLog for the iOS and AndroSensor for the Android operating systems, were chosen because they had similar recording features and produced files with a high degree of similarity that students could later open in Excel. The similarities between the apps themselves and what they produce would conceivably allow for smoother transitions as students were shuffled into new groups after roughly every other lab.

The two apps performed satisfactorily within the lab setting, but it was clear that the interface could be substantially improved upon. A great many issues were realized during the first semester of the study. (More detail on this is provided in section 9 on App Design.) Some of the issues were due to the apps' somewhat counter-intuitive user interface, some were due to a lack of understanding of how the hardware records data, and some were due to a lack of clarification by either the lab manual or the TA.

The first two of these pedagogical obstacles are later addressed by a new app. The app did not undergo serious development until the third semester of the study, when a portion of the project became funded by North Carolina State University's DELTA (Distance Education Learning Technology Applications) group. The third of these major pedagogical obstacles are addressed in the new edition of the MyTech TA Manual supplement, which is included in Appendix A.

5.2.2. Objective 2: Development of a Suite of Labs

In order to enable the inclusion of smartphones as data collection devices, the series of current mechanics labs needed adaptation. This process is described at length in section 4 on the Lab Curriculum Design.

The primary goal of the new suite of labs was to implement the new personal equipment with as few changes as possible. As was previously mentioned, the incorporation of the new devices demanded the addition of a few more conceptual questions.

As the study progressed throughout the three semesters, observations of students' performance of the labs helped guide the fine-tuning of the lab suite. The lab manuals trended toward the inclusion of more technical details and sometimes fewer requested experimental trials (as each trial was considered both more prolonged and more accurate than their traditional equipment counterpart). Details about how each lab was adapted can be found in section 4 on Lab Curriculum Design and the full lab manual is available in Appendix C.

5.2.3. Objective 3: Determination of the Learning Benefits of the Labs

People are excited about mobile devices in classroom and lab room settings. In addition to the ‘iPhysics Labs’ column (Kuhn & Vogt, 2012a), posters and presentations centering around this study—and specifically about the adapted lab curriculum—have generated interest at several regional and national conferences.

But before becoming too hasty in the implementation of these devices, it is important to carefully consider the educational impact of these labs and the inclusion of students’ own personal devices into them. It would be ill-advised to commit carelessly to the surface feature of these labs, which could be considered by some to be a novel—yet possibly gimmicky – approach to data collection.

Thus, as will be described in a greater detail later in this section, a series of pre- and post-semester tests were administered to the students in both the control and MyTech sections. In addition, students’ responses to individual conceptual questions were collected and analyzed to provide further insight into the learning benefits of the labs.

5.2.4. Objective 4: Determination of the Attitudinal Benefits of the Labs

In addition to seeking learning benefits, we are also interested in the new equipment’s effect on students’ attitudes regarding physics labs. In particular, we seek to determine the impact of lab equipment on students’ affect.

Our belief was that students would prefer to use their own devices in the lab. We conjectured this would be due to the students’ familiarity with the devices as well as the novelty of discovering the hidden capabilities of the smartphone. In either case, we anticipated that the implementation of this new equipment would be a stark improvement upon the prior equipment and that students' affective beliefs about their phones would positively shape their opinions of the lab course overall. Hence, we sought to examine the affective impact of these new devices on students.

5.3. Outcomes of the MyTech Study

In addition to fulfilling four objectives determined at the outset of the MyTech study, the project also produced several other unforeseen outcomes.

5.3.1. Outcome 1: Construction of a Software Tool for Educational Researchers to Aid in Coding Video Data

The video recordings of students performing the labs contribute largely to the richness of qualitative and quantitative data obtained throughout the course of this project. They provide an important key to understanding students' attitudes regarding the labs as well as the ways in which they spend their time in the lab. As a result, it was imperative that the 157 individual videos (of approximately 1.5 hours in length each) be systematically coded, with the video coding process being as time-efficient as possible. It became necessary to write two Visual Basic scripts (running within Excel) to achieve this goal.

Visual Basic is a programming language created by Microsoft in the early 1990s. It evolved from the BASIC (Beginner's All-Purpose Symbolic Instruction Code) language and was similarly easy to learn. Visual Basic for Applications (VBA) is a "dialect" of Visual Basic and is used in all of the Microsoft Office applications (Microsoft, n.d.).

While the scripts were originally programmed to streamline the video coding process for my initial sets of tags and videos, the constantly evolving set of tags encouraged the generalization of the scripts. The number of students in each group also varied more than was expected (between two and four members in each group). This furthered the motivation for a generalization of the video coding programs.

More details on the scripts and their generalization are included in a later section of this document on the Video Coding Analysis.

5.3.2. Outcome 2: Determination of the Feasibility of Using the MyTech Curriculum in a Series of Distance Labs

Throughout the course of the study, the mechanics labs were undergoing a simultaneous development of a different variation. eTALK, a project for “enhanced Teaching Assistance to aid Learning with Kitlabs,” was being developed by William R. Sams in the Physics Education Research Group under the direction of Dr. M. A. Paesler. The project aimed to take advantage of synchronous teaching assistance via online platforms in order to facilitate students’ learning gains in distance “kitlabs.”

This particular outcome will not be discussed in detail here, but will likely be discussed in detail in William R. Sams’ forthcoming dissertation.

5.4. A Statement about the Attempt to Discover the Attitudinal and Educational Impact of the MyTech Curriculum on Students at an All-Female College

There are differences between the ways that men and women interact with technology. Some of the studies that support this statement (Women in CE, 2013; Holland, 2013; “Infographic shows more women own smartphones than men,” n.d.; Gara, 2014) were discussed in section 2.4. Due to the scarcity of females in the engineering courses at North Carolina State University, we attempted to examine the attitudinal impact of replacing the traditional equipment with smartphones at an all-female institution.

Determining the educational and attitudinal impact on these students proved more difficult, as the standard testing measures and laboratory practices employed at Meredith College (the all-female institution of interest) differed greatly from those administered at NCSU. In addition, the concepts covered within the laboratory series at Meredith College contrasted sharply with those at NCSU, and thus only three labs were considered similar enough to compare. Finally, due to time and scheduling constraints, no “control group” was implemented at Meredith College. Hence, only three labs in one section of one semester were considered acceptable (and thus adapted, all other things being held constant) for the smartphone study.

Despite the limitations of the study at Meredith College, some effects of implementation of smartphones into physics labs conducted by females emerged from this study.

5.5. Research Questions

The development of the research questions evolved out of the MyTech study objectives. The four primary research questions, as they were stated during the preliminary exam, are laid out below, with questions that refine each of the research questions directly below them.

1. Do students gain physics knowledge?
   i. How do collaborative learning skills change?
   ii. How do analytical skills change?
   iii. Do students gain a deeper understanding of the role of experimentation?
2. How do students' attitudes about laboratory experience change?
   i. What is the evolution of affective and cognitive predisposition toward physics?
   ii. Does their self-confidence improve?
3. Will students use the devices outside of the lab?
   i. Do they become more aware of everyday physics applications?
   ii. What is the impact of having students connect in-class physics knowledge with out-of-class physics knowledge?
4. How does the implementation of these electronic devices affect the performance and attitudes of female physics students?
   i. Do their attitudes about physics change?
   ii. Is there any effect on their performance?

5.6. Evaluation Measures

In order to answer the research questions set forth in the preliminary exam, a series of evaluation measures were administered to students. With regards to students' gains in physics concepts, we recorded students' behaviors during the labs in the Qualitative Education Research Laboratory (QERL), a special classroom in the physics building that allows for observation behind one-way mirrors and audio-visual recording on four lab tables. Videos from the labs were then coded using activity tags. (For more information on the QERL, see section 5.1.) The coding produces temporal graphs that allow researchers to efficiently analyze students' behaviors in the labs. The videos from the QERL also produce qualitative data in the form of students' comments regarding the software (whether it be traditional or smartphone-related). Over the course of the three semesters, approximately 157 videos (each roughly an hour and a half long) were recorded of students performing both the smartphone and traditional labs. The videos are rich in quantitative and qualitative data.

Furthermore, a battery of tests and surveys were also administered at the beginning and end of every semester to both the traditional and smartphone groups. The TUG-K (Test of Understanding Graphs—Kinematics), an assessment published by Dr. Robert Beichner (a PI on this project) in 1994, was created to determine the viability of Video-Based Labs (VBLs) and was used in a similar way in this study to ascertain if any differences existed in the ways that students in the smartphone and traditional sections interpreted kinematics graphs. The test identifies the following common student errors in kinematics graphs: "graph-as-picture, slope/height confusion, variable confusion, non-origin slope errors, area ignorance and area/slope/height confusion" (Beichner, 1994). One example from this test uses graphs that "facilitate[e] pattern recognition in complex data." This is illustrated in the figure below (with a pie graph inlay demonstrating popularity of students' responses).

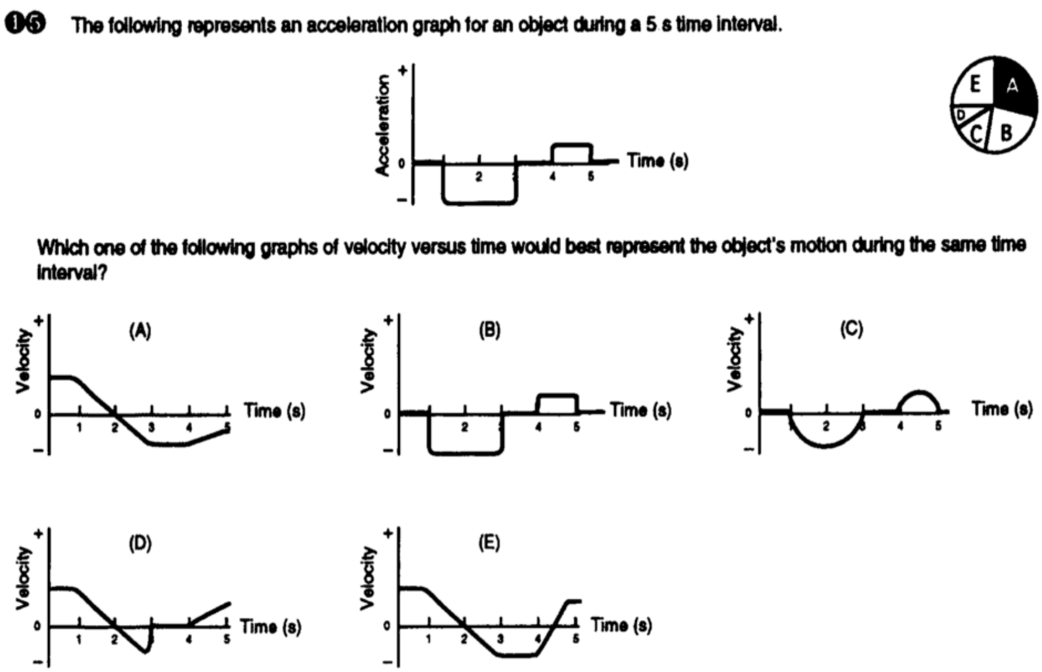


Figure 28 An example of an item from the Test of Understanding Graphs—Kinematics (Beichner, 1994).

The Colorado Learning Attitudes about Science Survey (CLASS) (Adams, 2005) was established as a validated and reliable measure of "various assets of student attitudes and beliefs about learning physics." The CLASS is to be given at the beginning and end of the semester to determine shifts in students' beliefs about their physics course. The measurement contains a series of statements about physics beliefs, and students are asked to rate, on a five-point Likert scale to what degree they agree with the statement. A CLASS specifically developed for experimental instructional laboratories was developed this past year (Zwickl, Hirokawa, Finkelstein & Lewandowski, 2014). Unfortunately, the E-CLASS (CLASS for Experimental Physics) was not released until after the start of the first semester of the MyTech study. Thus, the wording of the original CLASS was adapted only slightly to focus students' attentions on their lab courses as opposed to their lecture courses. For example in one statement on the CLASS ("I cannot learn physics if the teacher does not explain things well in class"), "in class" is changed to "in lab." For the sake of consistency, this adapted CLASS was used in all three semesters of the study.

Students' familiarity with and anxiety about technology was also investigated. To assess anxiety, the Computer Anxiety Rating Scale (CARS) (Heinssen, Glass & Knight, 1987) was used. Like the CLASS, the CARS consists of statements where students rate their agreement using a five-point Likert scale. Because the survey was developed in 1987, some of the verbiage was out of date. In an effort to modernize (but not alter the meaning of) the statements, the term "computer terminal" was replaced by "computer." We believe that these terms are synonymous and we therefore felt it was an acceptable replacement. In addition, to gain insight into how their anxiety using computers compares to their anxiety using mobile devices, two responses were requested of nearly all of the statements. Students were told to respond to the statement about the computer (marked "C") in one column and about the smartphone (marked "S") in the other. One statement, "I do not think I would be able to learn a computer programming language," was deemed only appropriate for the computer column, and thus, the smartphone column was blacked out, as shown in the diagram below.

Question	C	S
I feel insecure about my ability to interpret a graphical output on a computer/smartphone.		
I look forward to using a computer/smartphone in my day-to-day work.		
I do not think I would be able to learn a computer programming language.		

Figure 29 A portion of the Adapted Computer Anxiety Rating Scale.

On the back of the CARS questionnaire were several questions regarding technological usage. Students were asked to self-report items like how many hours a day they use their computer/smartphone, if they have ever used an app that allows them to collect sensor data outside of the lab (and, if so, what they measured), as well as their thoughts on using their smartphone in a physics lab. The questions were purposefully open-ended so as to determine shifts in usage as well as shifts in attitudes regarding smartphone usage inside the lab room.

This battery of surveys and tests (including the TUG-K, CLASS, CARS and technology usage survey) was administered to three semesters of students in the MyTech and traditional lab sections. In addition, standard course assessments (such as their lab assignments submitted through WebAssign) were collected. QERL data from all three semesters were used within the study, as well. The first semester's observations of student behaviors steered the improvements made in the following two semesters. The 157 videos from the second and third semesters' observations were coded in detail and subjected to inter-rater reliability studies to ensure consistency within coding. This process is described in greater detail in section 7.2.1.

Furthermore, as the study progressed into the third semester, we became increasingly interested in how students interacted with the app and the sensors (both in the smartphone and control groups). First, we wanted to determine whether or not students actually understood how the smartphone and traditional sensors collected the data. We believed that the first lab in the MyTech section of the course would have helped students understand how the accelerometer, in particular, records data. In contrast, we suspected students in the traditional lab section – given no explanation of how their sensors (like the force sensor) worked – would struggle to provide an accurate representation for how the data was collected. We administered a "lab equipment survey" to students in the MyTech and traditional sections during the last semester of the study. The survey consisted of two questions. The first asked students to rate their confidence (on a five-point Likert scale from "not at all confident" to "extremely confident") on how well they understand how the equipment used in the lab (such as the smartphone accelerometer, in the case of the MyTech students, or the spring sensor, in the case of the traditional students) works. The second question asks students to suppose that their 12-year-old brother came to visit their lab. At the end of the lab, he asks, "How did the phone measure acceleration?" (or, in the case of the traditional section "How did the spring sensor measure force?"). Students are asked to respond to his question. Diagrams were encouraged. We formulated the second question so that students would be more inclined to use simpler language that would appeal to a general audience.

Second, in the third semester of the study, we also wanted to harness students' difficulties with the pre-existing apps (AndroSensor and SensorLog) to determine what needed to be changed in a forthcoming edition of the MyTech app. The "smartphone app survey" was only administered to students in the MyTech section (as it was unlikely that students in the control section would have been aware of any of the pre-existing apps). Students were first asked a couple of simple questions regarding their app (which app they primarily used, and how they would rate the app on a five-point scale). Then, students were presented with a thoughtful list of eight common issues that we had observed students encounter while using the app. The list contained items like "figuring out how to change the recording rate settings," "figuring out how to graph the data in Excel," and "figuring out which axis to graph in Excel." They were also given an opportunity to write in their own issue. Finally, students were asked to respond to two questions aimed at improving the app (a yes/no question on whether a help feature or tutorial in the app could have helped them with these issues and an open-ended question about what changes or additions they would make if they could redesign the app). The results of this survey, as is discussed in section 9 on the proposed app design, informed the design elements of the upcoming MyTech app.

Tables summarizing the research design and methods of data collection are presented below.

Table 4 Data sources collected in over the three-semester comparative study

Sem-ester	Section	*n*	Pre-Test			Treatment		Post-Test					
			TUG-K	CLASS	CARS/Tech. Usage	QERL Observation	Video Analysis	Lab Equip. Survey	Smartphone App Survey	TUG-K	CLASS	CARS/Tech. Usage	Standard Course Assessment
Fall 2013	MyTech	12	✓	✓	✓	✓				✓	✓	✓	✓
	Trad	11	✓	✓	✓	✓				✓	✓	✓	✓
Spring 2014	MyTech	12	✓	✓	✓	✓	✓			✓	✓	✓	✓
	Trad	11	✓	✓	✓	✓	✓			✓	✓	✓	✓
Fall 2014	MyTech	11	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Trad	9	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓

Table 5 Data sources in the MyTech and traditional labs

	MyTech labs	Traditional labs
Pre-test	Pre-survey of skills (TUG-K) Pre-survey of attitudes (CLASS) Pre-survey of technology anxiety and usage	Pre-survey of skills (TUG-K) Pre-survey of attitudes (CLASS) Pre-survey of technology anxiety and usage
Treatment	QERL observation Video analysis	QERL observation Video analysis
Post-test	Lab equipment survey Smartphone app survey Post-survey of skills (TUG-K) Standard course assessment (summary question responses, sketches) Post-survey of attitudes (CLASS) Post-survey of technology anxiety and usage	Lab equipment survey Post-survey of skills (TUG-K) Standard course assessment (summary question responses, sketches) Post-survey of attitudes (CLASS) Post-survey of technology anxiety and usage

6. Educational Methods

As with numerous other course redesigns that include the implementation of new equipment, this study was guided by the work of other educational researchers. From the outset, the course’s use of new technologies required students to look more deeply at their own devices. Thus, it became important to consider the inclusion of new in-lab conceptual questions and the potential impact of these additional on the study design as well as the impact on the students in the study. In addition, another focus of consideration was the mixed methods approach of the study itself. The quantitative data (from the TUG-K, CLASS, and CARS) and qualitative data (from the transcripts of the videos and students’ free-form responses to various in-lab questions) needed to be analyzed in a structured manner. The implementation of mixed-methods approaches and grounded theory was essential in accomplishing this goal. Finally, since the new lab course was administered over three semesters with three different teaching assistant laboratory instructors, it was crucial to make use of a standardized measure of different teaching styles.

6.1. The Importance of Students Learning How the Equipment Works

Throughout this study, an attempt was made to clarify some of the inner workings of the smartphone and its sensors so that students might obtain a deeper meaning of their data or troubleshoot data collection methods with greater autonomy. To this end, in some of the labs, one or two additional questions were asked of students to get them to think about the way that the phones collect data. The first lab, “Discovering the Smartphone’s Axes” is an exception to this rule and was discussed in detail in section 4.1. The focus of this lab for both the control and experimental sections was to introduce students to the data collection and analysis tools they'd be using throughout the course. Due to the large distinctions in the equipment and software used for the two sections, these two labs were not comparable.

For the most part, these questions asked students to predict the appearance of their accelerometer graphs. Where possible, the data from these questions were separated from the other lab data so as to make the control and experimental sections more easily comparable. This portion of the lab manual for the second lab, "Free Fall," is reproduced below.

Objective

The purpose of this laboratory is to exercise your knowledge of the relationship among acceleration, velocity and distance.
You will then subject your device to a cushioned free fall and use its accelerometer data to determine an experimental value for g.

Free Fall

Procedure

1. Sketch what you think the acceleration versus time graph will look like when the smartphone is in free fall in the space provided.
   Be sure to label the time period that the phone is in the air. Your sketch need not have a scale for time.

Take a picture of your sketch and upload it to WebAssign.

Figure 30 A reproduction of a portion of the MyTech lab manual for the free fall lab.

These additional portions of the lab are supported by learning outcomes put forth by numerous physicists. Arnold B. Arons (1993), former president of the American Association of Physics Teachers, outlined some modes of inquiry that he suggested future teachers might utilize, including “subjecting a piece of equipment to close examination in context, figuring out how it works and how it might be used (rather than simply being *told* how it works and what it is supposed to do.” Furthermore, Arons goes on to illustrate this idea with an example involving the use of a ballistic pendulum. He suggests that students ought to first be able to design an experiment – even an imperfect one, without penalty of grade. Results from the first imperfect experiment can give way to discussion, critiques and, eventually, a new experiment with an improved design. This is exactly the philosophy behind the inclusion of accelerometer graph predictions. At first students may not fully comprehend the way in which data are collected on the smartphone, but through some trial and error (and with subsequent discussions and critiques), students should be able to arrive at a correct understanding of their lab equipment. This improved comprehension will hopefully result in a deeper appreciation of the experimental design of the lab.

The first struggle with how to handle students’ comprehension of lab equipment came alongside the arrival of digital meters and specialized electronic data collection tools. One paper from 1966 suggested that they “approve of such black boxes, as long as they are not too specialized; their functions are comprehensible and the student appreciates the need for calibration and checking” (King, 1966). More recently, the American Association of Physics Teachers (1997) released a series of learning outcomes for introductory physics labs. In it, they stress the need for students to become comfortable with their laboratory equipment to the point that “all laboratory students should have an opportunity to gain confidence in their ability to ‘troubleshoot’ and tinker with mechanical, thermal, optical and electrical systems.” This idea is furthered developed in their recent report on recommendations for physics lab curricula (Kozminski et al., 2014).

In addition to understanding how the equipment *collects* data, the AAPT report also the need for students to understand how to graph and otherwise analyze the resulting data. Despite attempts made at the outset of the semester to improve students’ understanding of the internal smartphone accelerometer and gyroscope axes, they continued to struggle throughout the semester with this concept. The problem became most evident when they tried to graph accelerometer or gyroscope data in Excel. In an absolute worst-case scenario (one in which they would not have followed the lab instructions accurately), MyTech students would open their accelerometer data in Microsoft Excel and be presented with a dizzying array of values (Table 6). These MyTech students were usually able to determine that they wanted to graph one of the three columns with “acceleration” in the title, but were often confused as to which of the axes (*x, y* or *z*) they should attempt to graph. Thus, some of the other questions added to the MyTech lab curricula encouraged students to consider the axis of interest *prior* to graphing the data. One such example from lab 4, “Impulse and Momentum” is displayed below:

✎ What is the axis of interest *on the smartphone* as it moves toward and away from the spring?
(In other words, which smartphone axis' data are you most interested in analyzing?)

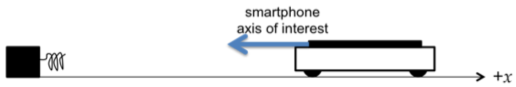


Figure 31 The MyTech lab manual contained a few additional questions involving the positioning of the smartphone.

Table 6 The Excel spreadsheets produced by the smartphone app can be quite large. Students needed to be able to identify which columns to graph.

The AAPT underlines the need for such devotion to this analysis in their lab outcomes, stating that "[s]tudents should be able to choose appropriate plotting methods to represent their data and should be able to fit their data and extract physical quantities from fit parameters" (Kozminski et al., 2014).

6.2. Mixed Methods Research

As previously mentioned in section 5.6, Evaluation Measures, a large number of both qualitative and quantitative data sources were utilized in this MyTech study. A brief summary of the data sources and the research questions they answer are presented below.

Table 7 Qualitative (QUAL) and quantitative (QUAN) data sources and the research questions they seek to answer

Research Questions	QUAL Data Sources	QUAN Data Sources
What is the added value of MyTech instruction in student learning of physics concepts?	QERL observation (student comments related to equipment interactions; cases of data fabrication) Lab equipment survey (explanation question) Standard course assessment	QERL observation (coded time length) Lab equipment survey (confidence level) Pre/post surveys of skills (TUG-K)
What is the added value of MyTech instruction in student attitudes about lab experience?	QERL observation (students' emotional comments)	Pre/post surveys of attitudes (CLASS) Smartphone survey (student rating of app)
What is the added value of MyTech instruction in student use of devices out-of-school?	Post-survey of technology usage (inside and outside class).	Pre/post-survey of technology anxiety and usage.

In this study, we made use of two mixed-method evaluation designs. First, to determine the impact of the MyTech equipment and curriculum on the students, we used the complementarity method (Greene, Caracelli, & Graham, 1989) to enhance the quantitative results with qualitative data sources, and vice versa. For example, students' emotional comments regarding the lab equipment and their teaching assistants give credence to the quantitative results we obtain in the video coding schema. Furthermore, students' answers to free response questions in the labs can also provide insight into their TUG-K scores.

"Triangulation" of qualitative and quantitative data is often confused with "complementarity." Triangulation focuses on overcoming biases inherent to specific data sources by including others with offsetting biases. For example, a researcher might administer a quantitative questionnaire and a qualitative interview that attempt to investigate the same facet of a study (Greene et al., 1989). Conversely, a researcher using the a mixed-method evaluation design of "complementarity" seeks to measure "overlapping but also different facets of a phenomenon, yielding an enriched, elaborated understanding of the phenomenon." Using complementarity, then, we seek to determine the impact of smartphone implementation in introductory mechanics labs using multiple data sources. The phenomenon (the educational impact on students) is broad, and therefore necessitates the use of multiple forms of quantitative and qualitative research.

Secondly, we used the "development" method (Greene et al., 1989) to design the MyTech app survey around student feedback. This will be discussed more in section 8.5. In this way, we used comments obtained through student observations (qualitative data) to develop a survey about app design (quantitative data). As an example, see one question from the app survey shown below:

3. Please circle any issues (may be more than one) you may have encountered while using the app.

    a. Having trouble reading the graph inside the app
    b. Having trouble reading the values for a_x, a_y and a_z inside the app
    c. Finding or using the record button
    d. Figuring out how to change the recording rate settings
    e. Figuring out how to email the data
    f. Figuring out how to graph the data in Excel
    g. Figuring out which axis to graph in Excel
    h. Realizing you have too few data points in Excel

    i. Other(s):

Figure 32 One question on the Smartphone App Design survey asked students to identify, from a series of common issues, what problems they encountered with the app.

All of the pre-written possible choices for response (options a through h) were real issues encountered by students in the MyTech app curriculum.

6.2.1. A note about the evolution of the MyTech Curriculum

The MyTech curriculum was not the result of sole *invention*. Instead, experience with NC State existing introductory mechanics physics laboratory curriculum played a large part in its *adaptation* to include smartphones and webcams as data collection devices. Henderson and Dancy (2006) draw the distinction between these two styles of implementation on their “adoption-invention continuum.” In this way, faculty at NC State created the curriculum, which I modified slightly (without making any fundamental changes to principles).

Throughout the course of the three-semester-long study, the curriculum was tweaked and “redeveloped” due to student feedback obtained through surveys and video data. Redish (2002) describes this process as his “research and redesign wheel” and illustrates it with a three-spoked wheel where the model of the learner influences the three nodes of the spokes: research, curriculum development and instruction.

The MyTech curriculum (adapted from the traditional mechanics lab curriculum) was put into place, student feedback pointed out unforeseen issues, and a refined curriculum was put into place the following semester so that the cycle might begin again.

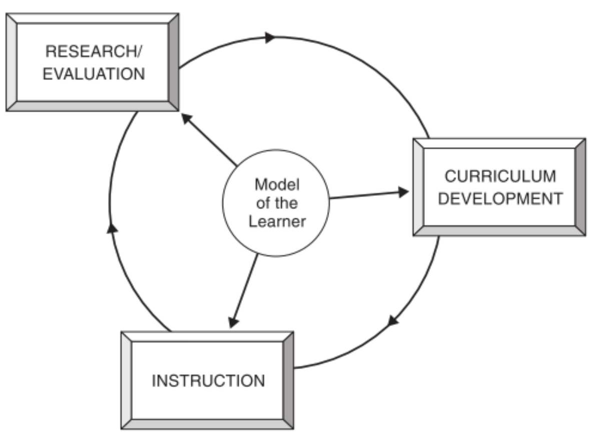


Figure 33 The "research and redesign" wheel (Redish, 2002).

6.3. Grounded Theory and Temporal Analysis of Students' Activities

Just as the creation of the MyTech curriculum was fluid and resulted from student feedback in conjunction with research, the analysis produced by the MyTech study was also a free-flowing process within a feedback loop. Theories resulting from the study must be grounded in the social research itself and must emerge from the data. Instead of attempting to verify a theory, the idea of grounded theory focuses on the emergence of a new theory from data (Glaser & Strauss, 1967). Categories are generated by the data and the data are used to illustrate the concept of that category. Grounded theory, in its initial formulation, uses both qualitative and quantitative data together as "mutual verification" as "different forms of data on the same subject." This idea is less consistent with the mixed-method design of "complementarity" and more on "triangulation." Thus, for the purposes of this study, the definition of "grounded theory" will be extended to include different forms of data on *similar* (but not necessarily the *same*) facets of a singular phenomenon. The general process of implementing grounded theory consists of three main ideas:

1. Code the data. Attempt to find patterns within the data (videos, interviews, etc.) for which you can define categories and see if the impressions fit. This step is typically done quickly so as to discover first impressions.
2. Recode the data. As you make more and more observations, the categories that emerged initially might evolve and form different emergent categories. These new categories will necessitate a recoding of the data.

3. Continue to repeat step 2 until the categories become less fluid and the current set of categories is sufficient for the data set.

The primary tenet of grounded theory is that "a theory should only be replaced by a better theory." Throughout all steps of the process involving grounded theory, the researcher should be engaged in a continual internal dialogue. In grounded theory, one "grounds theory in the social research itself" by generating a theory from the data.

In this study, grounded theory was used most often in the establishment of video coding categories. In the first semester of the study, I began to compile a list of activity tags that might be appropriate to the behaviors of the students. We focused on student-equipment interactions in hopes of gaining insight into the first and second research questions. As you will find in the results of the video data, I could have perhaps considered creating another research question regarding the *nature* of students' equipment interactions in the coursework. In order to help us answer the first research question ("What is the added value of MyTech instruction in student learning of physics concepts?"), we attempted to create a temporal analysis of the students' activities within the lab. The idea was inspired by a research group at University of California at Davis in which researchers watched videos of grouped students in their physics classes (West, Paul, Webb, & Potter, 2013). The UC Davis group wanted to compare how time was spent in the class during "small group time" and "whole class time." To accomplish their goal, they quantified the amount of time spent in various activities. They developed a Real-Time Instructor Observation tool (RIOT), a computer program which allowed them to code data as they observed teacher-student interactions in real time. Graphs produced by this program are shown below.

In the MyTech study, similar graphs were produced using software developed in Visual BASIC. Instead of eight broad categories (as with the UC Davis study), many more categories emerged using grounded theory.

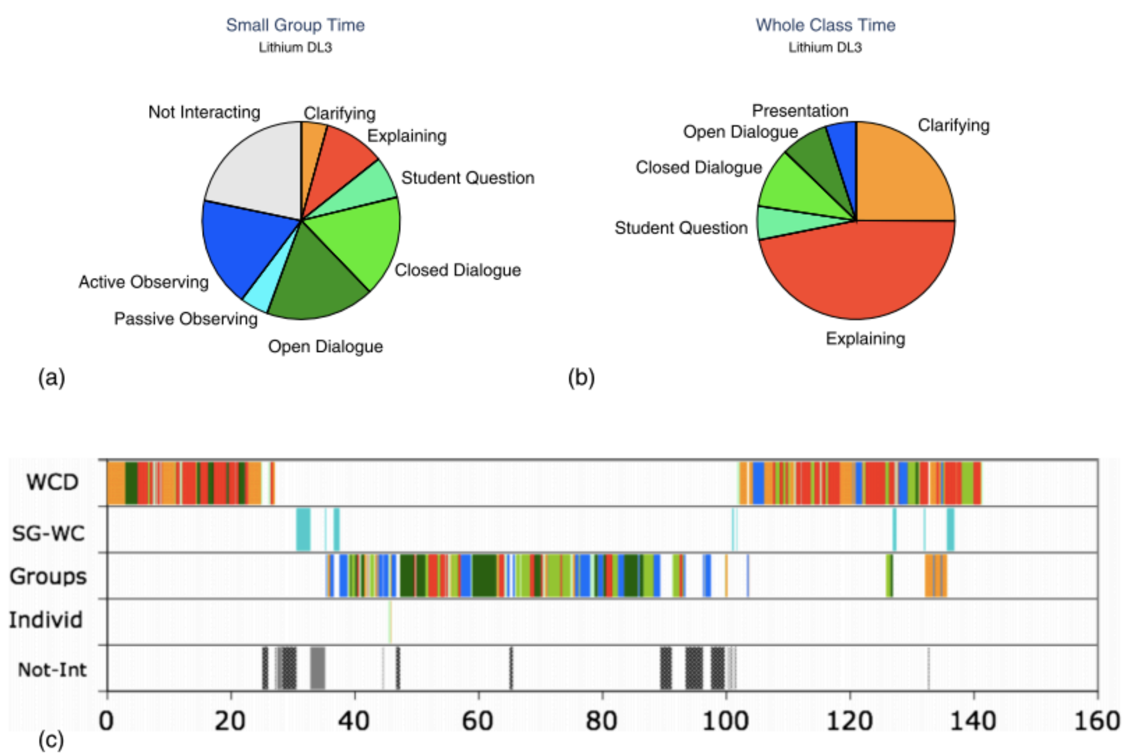


Figure 34 Examples of the graphs produced by the Real-Time Instructor Observation Tool (West, et. al, 2013).

First, an initial set of categories emerged from the data through real-time observation of the first semester of the MyTech study. These activity tags were used to code video data for the first four labs of the second semester to determine their sufficiency. During the second step of the process of grounded theory, tags were created, destroyed and subsumed into others. The tags were then used to re-code the first four labs of the second semester. No changes were deemed necessary, and thus, the second (current) set of activity tags used in the video analysis of this study was formed.

6.4. Teaching Belief Interview

Throughout the course of the video coding, we observed strong differences in the way that students spent their in-lab time in the separate semesters studied. Some of these differences could be attributed to the small sample size of students in the study (which between nine and twelve students a semester). A more likely explanation, however, is that the disparities are due, in part, to differences in the observed ways that the teaching assistant handles the class.

In order to examine some of these ideas, all three of the TAs were given the Teaching Beliefs Interview (Luft & Roehrig, 2007) (TBI). As was done with other studies (LePrevost, Blanchard & Cope, 2013), the TBI was adapted slightly so as to be most relevant to this study. The questions bore the most resemblance to those used in a study of graduate teaching assistant beliefs in a laboratory setting (Addy & Blanchard, 2010). The difference between the TBI administered in that study and this one was the addition of question 8, specific to the MyTech study.

1. How do you maximize student learning in your laboratory?
2. How do you describe your role as a laboratory instructor?
3. How do you know when your students understand?
4. In the laboratory setting, how do you decide what to teach and what not to teach?
5. How do you decide when to move on to a new activity in your laboratory?
6. How do your students learn science best?
7. How do you know when learning is occurring in your laboratory?
8. Did you prefer to teach the smartphone labs? Or the control section? Why?
9. What are your final comments?

The Teaching Beliefs Interview helped affirm some of the classroom observations. The only semesters that were video-coded were the last two semesters of the MyTech study. The first semester was primarily used as a pilot program since we used it to determine major issues that needed to be addressed and fixed in future semesters. Thus, attention is focused on TA2 (from the second semester) and TA3 (from the third).

Classroom observations led to the conclusions that TA2 was generally more distant and less proactive than TA3. A summary of characteristic actions for TA2 and TA3 are presented below:

Table 8 A comparison of TA2 and TA3

TA2 (Spring 2014)	TA3 (Fall 2014)
Has at least two years experience	First-semester TA
Distant	Proactive, engaged
Rarely addressed entire class at the beginning of the lab	Often addressed entire class at the beginning of lab with general procedural hints
Rarely made use of whiteboard	Presented pertinent equations or figures on the whiteboard before students encountered questions
Tended to only speak to students that directly asked for his help	Constantly circled the classroom, seeking out those that needed help
Promoted a quiet, professional lab room	Chatted with students

We should qualify the characteristics above by stating that these are my own observations and have not been verified with inter-rater reliability. Many of these statements, however, were corroborated with statements made by the TAs during their Teaching Beliefs Interview. Transcripts are available in Appendix B.

7. Video Coding Analysis

The sample size of the study was quite low so, to obtain as much data from the study as possible, we gathered detailed recordings of students' interactions with the equipment, with other students and with the teaching assistant. Here, we replicated the RIOT approach

(West et al., 2013) of temporally analyzing the videos of students' group work in the MyTech and control labs.

Several aspects of RIOT were desirable and thus the program served as a great "jumping off point" for a researcher tool of our own. The graphs produced by RIOT are easily comprehensible and do not require a great deal of training to interpret. Additionally, the RIOT was easy to use and thus extremely beneficial for a project containing over 150 videos, averaging about one and a half hours each.

The utilization of the RIOT approach necessitated a series of changes to the program itself, to the point that a new program would be created in its stead. First, the MyTech activity coding did not take place in real-time. MyTech activities were coded after the lab was over so that the researcher could focus on issues encountered within the labs (some of which needed immediate attention) as they occurred from within the QERL. Secondly, the original RIOT focused on student-teacher interactions. Thus, the categories determined within their schema were not appropriate for the MyTech study, where the focus was on the student-equipment interactions. Furthermore, the original RIOT was written in FileMaker Pro (Paul, 2012), which required expensive and somewhat uncommon software. Since the inception of the VOT, the RIOT has since been made available as a Google app (Paul & Reid, n.d.).

These changes necessitated a new program. The purpose of the Video Observation Tool (VOT) was diminish the tedium associated with video coding and allow researchers to focus on the students' activities in the videos themselves as opposed to the act of recording the activities.

The VOT program consists of a series of Visual BASIC scripts within Microsoft Excel, since both BASIC and Excel are ubiquitous and most researchers are familiar with them. VOT allows for researchers to define the activity categories, to assign colors to them and to simultaneously code the activities of up to four students in a group. The VOT then outputs two types of graphs, similar to those produced by the RIOT: (1) a pie graph for each student, which allows for a quick overview of the way the time was spent in the lab and (2) a temporal analysis graph, which takes the form of a horizontal bar chart, and allows researchers to determine the chronological order of the students' activities, as shown in Figure 43. The colors in the two types of graphs are internally consistent and match the colors originally assigned to each activity code.

7.1. Using the Video Observation Tool

The next several pages outline the general procedure quantitative and qualitative researchers can employ when coding videos of their students.

7.1.1. Opening the VOT

1. The user first opens the VOT Excel file.
2. Upon opening the file, the user will be prompted to disable macros. In this case, the "macros" are synonymous with the VBA scripts, and thus the essential element in the file. Assuming one has downloaded the file from a trusted source, choose "Enable

macros."

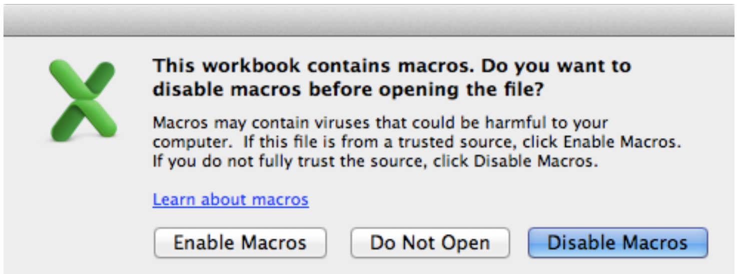


Figure 35 Microsoft Excel will prompt the user to enable or disable macros.

3. The VOT script should run automatically and the user will then be prompted to enter his or her initials. The purpose of this was to allow for researchers to easily compare spreadsheets that they produced to those that their fellow researchers produced during inter-rater reliability studies.

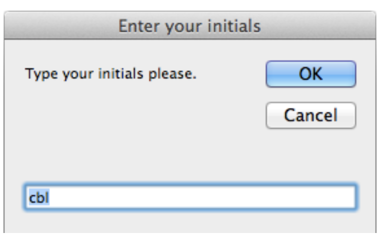


Figure 36 The Video Observation Tool will prompt users for their initials.

4. The Video Observation Tool should then open.

Figure 37 The Video Observation Tool.

Note: Once the VOT is open, the researcher can only directly access the Excel spreadsheets by closing out of the VOT and reopening it when ready.

7.1.2. An Anatomy of VOT

The VOT is broken into five vertical panels. The first four allow activity coding for up to four students (S1, S2, S3 and S4). The fifth allows the user to control group-wide statistics and to produce the temporal analysis graphs.

The VOT records each student's data to a separate sheet within the Excel workbook file. The figure below illustrates the recorded data on one student's sheet.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**Physical Equipment Interactions**	**Software Interactions**	**Intra-Group Interactions**	**Inter-Group Interactions**	**TA Interactions**	**Other**	**EndTime**	**Code**	**Delta T**	**Time of Coding**					
2						Other > NA	311	Other > NA	311	31/01/2015 18:15:52	cbl		0	5	11
3	pe > SPrep						406	pe > SPrep	95	31/01/2015 18:16:35	cbl		0	6	46
4	pe > SRcd						467	pe > SRcd	61	31/01/2015 18:17:08	cbl		0	7	47
5	pe > SPrep						624	pe > SPrep	157	31/01/2015 18:18:31	cbl		0	10	24
6					TA > Chat		647	TA > Chat	23	31/01/2015 18:18:38	cbl		0	10	47
7			intra > STopic2				715	intra > STopic2	68	31/01/2015 18:19:16	cbl		0	11	55
8		sw > TAMsrdSw					1034	sw > TAMsrdSw	319	31/01/2015 18:21:53	cbl		0	17	14
9	pe > SPrep						1246	pe > SPrep	212	31/01/2015 18:23:42	cbl		0	20	46
10		sw > SRcd					1277	sw > SRcd	31	31/01/2015 18:23:52	cbl		0	21	17
11		sw > TAMsrdAn					1289	sw > TAMsrdAn	12	31/01/2015 18:24:01	cbl		0	21	29
12		sw > SRcd					1330	sw > SRcd	41	31/01/2015 18:24:20	cbl		0	22	10
13		sw > TAMsrdSw					1355	sw > TAMsrdSw	25	31/01/2015 18:24:33	cbl		0	22	35
14	pe > SPrep						1528	pe > SPrep	173	31/01/2015 18:26:01	cbl		0	25	28
15		sw > TAMsrdSw					1623	sw > TAMsrdSw	95	31/01/2015 18:26:46	cbl		0	27	3
16	pe > SPrep						1715	pe > SPrep	92	31/01/2015 18:27:31	cbl		0	28	35
17			intra > STopic2				1818	intra > STopic2	103	31/01/2015 18:28:22	cbl		0	30	18

Figure 38 A screenshot of an Excel spreadsheet containing the activities of one student. The spreadsheets are later user by the VOT to produce the graphs of temporal analysis.

Each row in the sheet represents one activity that S1 is engaged in. In the case illustrated above, S1 does nothing (tagged as "Other > NA" in columns F and H), for the first 05:11 of the video (displaying in columns M, N, and O for the hour, minute and second code). The program converts this "end time" into seconds (as shown in column G).

An "anatomy" of the first panel type of the VOT window illustrating some of its features is shown below.

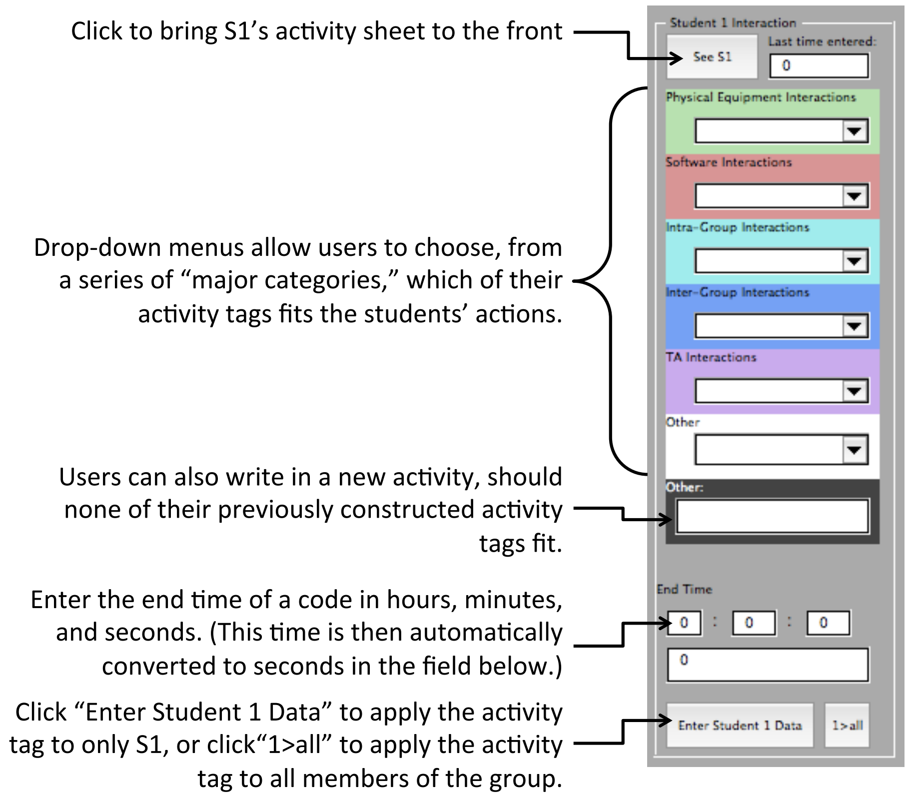


Figure 39 A breakdown of the first four panels of the Video Observation Tool.

7.1.3. Setting Up and Using the VOT

In order to use the VOT, one must determine the set of activity codes emergent in the data, their corresponding colors and, if applicable, the "major categories" to which they belong. To do this, one must close out of the VOT and click the "Code Colors" tab.

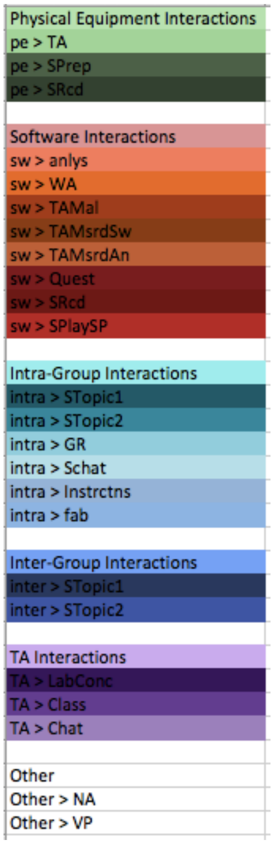


Figure 40 The first column of the "Code Colors" spreadsheet in the Video Observation Tool file contains the activity tags and their corresponding colors. Researchers can edit the labels and colors of each activity tag.

In order for one to enter his or her own codes and colors, he or she must clear the pre-existing codes and the color formatting. Major categories should be separated by one row. The number of major categories is currently restricted to under six due to the spatial limitations of the VOT's interface. Others with more major categories could consider combining the activity codes from two or more for the purposes of using the VOT. We hope to improve this feature in future versions. The color-coding for this project was chosen so as to easily differentiate codes within major categories. In addition, the "software" major category was emphasized with various shades of red and orange so as to stick out from the other cooler-colored categories. (This color schema was chosen for this project alone and is only a suggestion to other researchers who must keep in mind that a substantial portion of the world is red-green color blind.) The colors chosen here will be the same as those used on the graphs produced by the VOT.

Once one has entered the codes and their corresponding colors, he or she should reposition the Excel window and movie windows in preparation for running the VOT, as shown in the screenshot below.

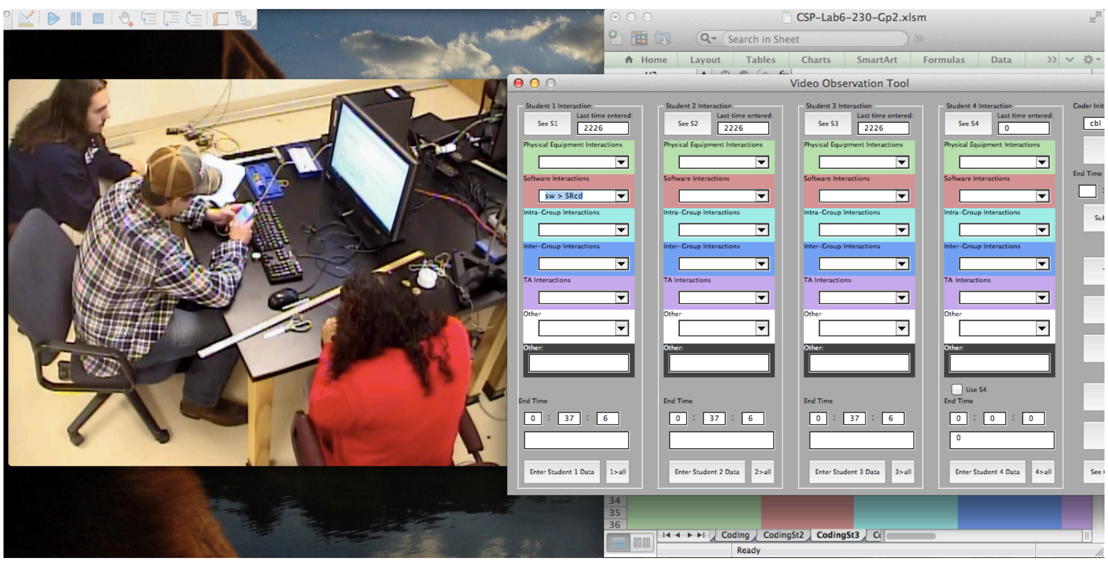


Figure 41 A screenshot of the VOT (right) while one is simultaneously watching video of students in a MyTech lab (left).

To run the VOT, the researcher can click “Run Macro (⏵)” (or find the “Tools > Macro > Macros…” menu) and choose “OpenCodingHelper.” The drop-down boxes should be automatically populated so as to match the new set of codes.

7.1.4. Producing the Temporal Analyses

Once the coding process is complete and the entire video has been analyzed, one can instruct the VOT to produce a series of temporal analysis graphs, similar to those produced by the RIOT. To do this, one must turn our attention to the fifth panel of the VOT.

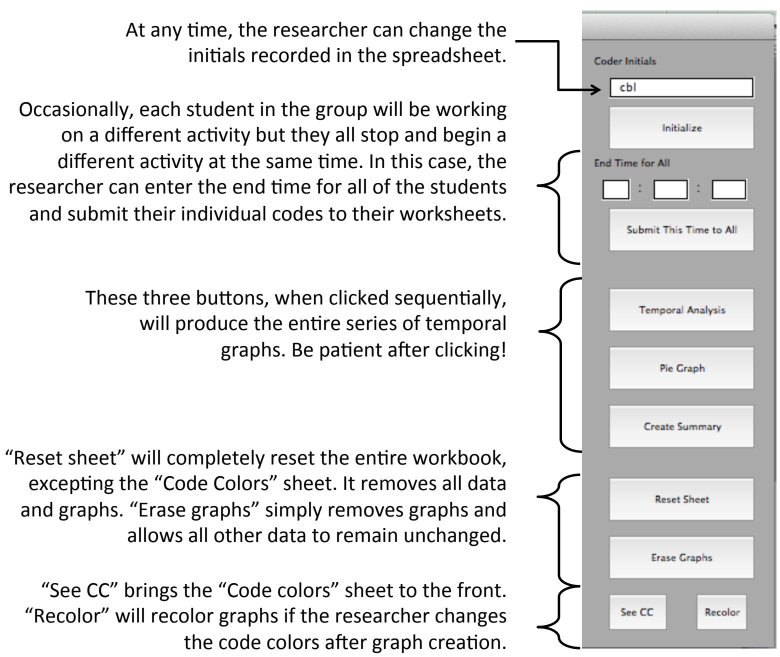


Figure 42 A breakdown of the fifth panel of the VOT.

After completion of data entry, one should click “temporal analysis.” After a brief delay, the horizontal bar graphs displaying students’ activities throughout the lab should appear in each student's coding worksheets ("CodingSt1," "CodingSt2," etc.). Then, one should click "Pie Graph." The delay here is data-dependent and often quite significant (about 15 seconds for the files used in this study). One knows when the process of creating the pie graphs is complete when they are once again prompted for their initials. During the "Pie Graph" stage, the total time for each individual code and major category is tabulated per student in the "Code Colors" tab. Pie graphs for the major categories and individual activity codes are created. Finally, one can choose to "Create Summary." In this stage, a new worksheet titled "Summary" is created and all of the pie graphs and bar graphs are displayed in one place.

In the case of this project, these "summary" sheets were the source of the compilation of *all* data across all of the labs. Many researchers may not find this step necessary.

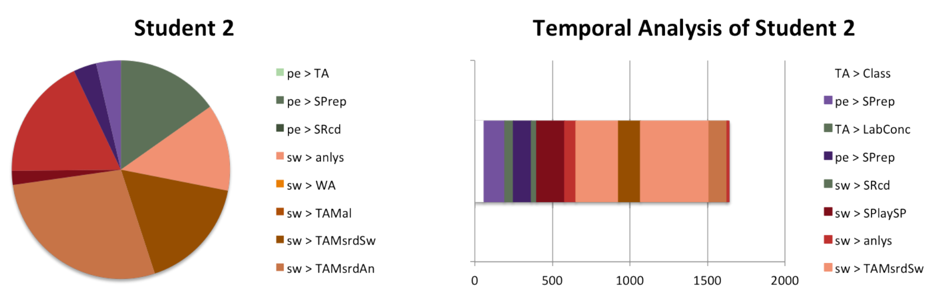


Figure 43 Sample temporal analyses produced by the VOT. These particular samples were taken from a MyTech student working through Lab 3 in Fall 2014. The horizontal axis in the second image is time (s) in the class. Each color represents a different activity that the student worked on during any given time.

7.2. Quantitative Video Analysis

Over the course of the three-semester study, only 35 students interacted with the MyTech curriculum and 31 students with the traditional curriculum, as shown in the table on page 85. Therefore, gaining meaningful and statistically significant differences between the two curricula was difficult with the standard measures like CLASS for attitudes, TUG-K for kinematics skills, and the adapted CARS for technological anxiety. In order to ascertain significant differences in the educational impact on students, we looked to the video data. The videos of students working through labs provided us with the richest source of data, by far. In addition to gaining qualitative data via students' comments throughout the lab regarding equipment usage, the VOT allowed us to quantitatively investigate subtleties (with extremely fine temporal resolution) in the ways that students appropriated their time in the lab.

We used qualitative observations regarding the ways in which TAs interacted with students throughout the two semesters of video coded data to confirm that the VOT method of coding video data was sensitive. After this verification, we could then use the results of the VOT method to draw conclusions about how the MyTech curriculum affected students' behaviors in their mechanics labs.

In order to ascertain that the VOT protocol for video coding was sensitive to differences between the MyTech and traditional *curricula*, we first investigated whether or not it could quantitatively confirm the anecdotal differences we were seeing between semesters. The second semester TA for both the MyTech and traditional sections (TA 2) was quite unlike the third semester TA (TA 3). As a reminder, the first semester of the MyTech study was effectively used as a means of feasibility research, and thus was not video coded.

The Teaching Beliefs Inventory did not reveal any statistically significant differences between TA 2 and TA 3, however, the two TAs' interactions with students and equipment were quite disparate. The two semesters' sections also "felt" quite different from an observation perspective. I suspect that this was primarily due to TA interactions, but it is possible that the students in the second semester differed from those in the third.

TA 2 had a few years of TA experience in PY 206. He was intimately familiar with the traditional labs. He owned a smartphone, but had not investigated apps like SensorLog or AndroSensor prior to TAing the course. In addition, although TA 2 was provided with the MyTech lab procedure in the week prior to that MyTech section, he was rarely familiar with the instructions. Students in his labs were expected to sit down and begin the lab right away as TA 2 often did not introduce the lab or address the whole class for more than a minute. His position "defaulted" to the TA instructor computer station and tended to only interact with students if the students themselves raised their hands to initiate the conversation. Students in TA 2's labs were therefore more autonomous but were apt to struggle more with the lab on their own than with other TAs. The second semester students were very quiet and studious and often relied upon their teammates more than the TA. Even intra-group conversations under the direction of TA 2 were less frequent than intra-group conversations that occurred under the instruction of other TAs.

In contrast, TA 3 was a first-year TA. Although he did not have previous semesters' experience with these labs, he did have the opportunity to run through the traditional labs earlier in the week, prior to entering the MyTech classroom. TA 3 owned a smartphone and attempted several of the MyTech lab activities prior to TAing the class. He was an incredibly proactive TA and constantly circled the classroom, engaging students in conversation about procedural and conceptual topics. Often times, he would even give them helpful hints to solving common issues prior to the group's encountering of those issues. As he circled the room, he would often participate in students' off-topic conversations. Students in his lab were quite chatty and both the MyTech and traditional sections were "abuzz." The third semester students were therefore communicative and would often call TA 3 over for help with little attempt to troubleshoot problems on their own. A table summarizing the TAs' and students' characteristics between the two semesters is provided below.

Table 9 A comparison of TAs' and students' characteristics between the two semesters of video coded data

	MyTech Section	Control Section	Coded?	TBI Score	Anecdotal Observations
Fall 2013	TA 1			2.86 ± 0.84	
Spring 2014	TA 2 Fourth-year TA		✓	2.07 ± 1.02	Aloof TA; Quiet/serious students
Fall 2014	TA 3 First-year TA		✓	2.69 ± 1.40	Proactive, chatty TA; Students tended to engage in off-topic conversation

The above descriptions of the TAs and students are based on my own observations developed prior to seeing any quantitative results. While attempts were made to remain as objective as possible, the descriptions did not undergo inter-rater reliability analysis.

We attempted to minimize the impact on the study of any direct researcher-student interaction. Occasionally, however, the TAs needed additional help guiding the students' MyTech and traditional lab activities. I made myself available during class time to the TAs in the QERL's neighboring observation room. At any point, the TA was welcome to come in and ask me a question. Throughout each semester, there were few instances of TAs needing help with a computer or smartphone. In these rare cases, I entered the classroom and assisted the TA. This may have possibly impacted some of the results below.

Each video displayed one group's activities in one section of one lab. The videos averaged about an hour and a half in length. Due to complications with weather cancellations of class, the second semester of the study contained only 10 of the 11 labs. In total, I coded 157 videos over the two semesters.

Table 10 Sources of video data

	Section	# Labs	# Groups	Total # Videos
Spring 2014	MyTech	10	4	40
	Control	10	4	40
Fall 2014	MyTech	11	4	44
	Control	11	3	33
				157

7.2.1. Activity Tags

A series of activity tags emerged from the videos for this study. The activity tag creation process necessitated special care regarding student-equipment interactions. Student-student interactions and student-TA interactions were also taken into account, but to lesser detail than the equipment interactions.

Six of the 11 labs in the PY 206 also required that students work through problems involving VPython simulations. These simulations remained completely unchanged from the traditional course and have been partially analyzed in other studies. Thus, the student-student and student-TA interactions that took place during these simulations were not analyzed.

The tags were broken up into six major categories: physical equipment interactions, software interactions, intra-group interactions, inter-group interactions, TA interactions and all other interactions. Each category was further subdivided into multiple "activity codes," which provide examples of events that would have been coded under these categories.

- Physical equipment interactions: For the purposes of this study, “physical equipment” is defined as the equipment common to both the traditional and MyTech curriculum. In this way, “physical equipment” includes carts, balls, tracks, pendula, meter sticks, calipers, springs, turntables, etc. TA interactions that directly involve setting up or using physical equipment were also included in this major category.
    - **pe > TA:** TA helps students understand how to use or set up physical equipment, helps a student with physical equipment malfunctions or with a misunderstanding regarding physical equipment.
    - **pe > SPrep:** Student sets up physical equipment.
    - **pe > SRcd:** Student actively records data using physical equipment.
- Software interactions: This major category is of considerable interest to this study. Here, “software” involves any of the devices and programs used to collect and record data in the lab. In this way, “software interactions” involves students’ use of smartphones for collection of data and off-topic tasks, Excel or calculators for analysis, DataStudio for data collection and analysis, as well as any time students spent with WebAssign (the online instructional platform used for physics lab data entry). The “analysis” activity code was by far the most often used tag as it encompasses a wide variety of activities, including calculations with a calculator, Excel analysis, DataStudio analysis and Tracker video analysis. TA interactions that involved software malfunction, or students’ misunderstanding of how the recording or analysis software worked were also included in this major category.

- **sw > Anls:** Student works through the mathematical analysis of their data, either by hand or by opening Excel or their calculator. They do not have to be using smartphone or computer software; student uses Tracker software or DataStudio to analyze data.
- **sw > WA:** only use this code if WebAssign (e.g., “WebAssign marked this wrong” as opposed to a conceptual question in WA) is the focus of the conversation, if one student is simply entering into WA, or if a student uses their smartphone’s camera to take pictures of their hand-drawn sketches in order to upload them to WebAssign.
- **sw > TAMal:** TA helps students with software/smartphone malfunction.
- **sw > TAMsrdSw:** TA helps student with misunderstanding regarding software or hardware (e.g. interface with device is wrong). This code trumps SRcd if TA is present and engaged in the interaction.
- **sw > TAMsrdAn:** TA helps student with misunderstanding regarding analysis concepts/software (e.g. linear regression, graphing).
- **sw > Quest:** Students answer questions specifically about how the sensor(s) record data. This activity tag includes students attempts at any questions about *a*-vs.-*t*, *v*-vs.-*t* or *d*-vs.-*t* graphs.
- **sw > SRcd:** Student actively records data, attempts to record data or prepares the software for use following laboratory instructions. This tag also includes students downloading sensor data onto their computer or changing the settings of the sensor apps. If a student uses his or her smartphone as a calculator, we treat as if it is a

standalone calculator (usually sw > Anls or ira > STopic1/2); if student uses his or her smartphone as a timer, treat as if standalone timer (usually pe > SRcd).

- **sw > SPlaySP:** Student "plays with" smartphone but it does not appear to be directly forwarding their progress in the lab.

- Intra-group interactions: In situations wherein the group is not actively participating in any of the aforementioned major categories (physical equipment or software interactions), students within a group were most often discussing the lab with each other. These discussions were classified into conceptual and procedural topics. Additionally, intra-group interactions can include other activities, such as chatting or fabricating data.
  - **ira > STopic1:** Students discuss on-topic, physically meaningful ideas ("Is energy conserved?") or answer conceptual WA questions, such as those that involve error analysis.
  - **ira > STopic2:** Students discuss on-topic, operationally important ideas ("How can we keep the pendulum from twisting?").
  - **ira > GR:** Students discuss their group roles (such as "manager," "skeptic," and "recorder") and enter their names into WebAssign.
  - **ira > SChat:** Students engage in off-topic conversation, whether inter- or intra-group.
  - **ira > fab:** Students fabricate (or strongly consider fabricating) data. This may or may not include a TA's encouragement.
  - **ira > instructions:** Students read instructions in silence.

- Inter-group interactions: This major category is an analog to the intra-group interactions, but have been classified only into conceptual and procedural topics.
  - **inter > STopic1:** Students discuss physically meaningful ideas about the labs with students with other groups.
  - **inter > STopic2:** Students discuss operationally important ideas about the labs with students with other groups.
- TA interactions: In this major category, the TA might address the whole class or just a group about lab concepts. Alternatively, the TA might chat with a group. These TA interactions were adapted from the RIOT paper[93].
  - **TA > LabConc:** TA discusses physics or math concepts related to the lab (but not directly to the equipment) with student. This might include clarification of instructions, discussion of issues with WebAssign not accepting an answer, TA verification (or "TA Checkpoints").
  - **TA > Class:** TA discusses lab concepts with entire class. This often occurs at the beginning of the lab period, but can also be tagged throughout the lab.
  - **TA > Chat:** TA engages in off-topic conversation with students.
- Other interactions: This major category includes all other possible student activities, including VPython simulations and "NA" for no participation in the lab whatsoever.

In order to provide a standardized coding method with the VOT for the purposes of inter-rater reliability, several "rules" were established:

1. Use dominant behavior to code. If students are chatting while analyzing data, you can say that they are primarily analyzing data. (For example, only use "Chat" if they are doing nothing but chatting.) The general hierarchy of activity dominance was determined with the intent of classifying the behavior that most advanced the group's lab work forward. Here is the general hierarchy of activity dominance:
    a. VPython Activities
    b. TA interactions
    c. Software interactions
    d. Physical equipment interactions
    e. On-topic discussion
    f. Reading instructions
    g. Chatting
2. Log only activities that persist for more than ten seconds. (For example, a student pulling a smartphone out of their pocket to check the time would not need the tag for "playing with a smartphone" unless this process took more than 10 seconds.) Obtaining agreement in inter-rater reliability studies with a time resolution of less than 10 seconds would be exceedingly difficult, and the added resolution would probably not have given any more insight.
3. Code all behaviors at the group level. In other words, the dominant *group* behavior would need to be determined using the hierarchy above and then recorded using the

VOT tool. While the VOT tool allows for individual student-coding, the differences between students' behavior within a group were *very* rarely significant.

After all 157 videos had been coded using the above VOT method and inter-rater reliability was reached with an undergraduate researcher, the data from all of the videos were compiled and a cross-section and cross-semester analysis ensued. We identified patterns within the data that led us to (1) verify the VOT method as a sensitive measure and (2) determine the temporal impact of the MyTech curriculum on PY 206 students.

7.2.2. TA-Influenced Behaviors

First, consider the temporal data that were strongly dependent on the TA. For each of the activity tags listed below, statistically significant differences ($p < 0.05$) were observed between the students' behaviors in Spring 2014 and Fall 2014. The differences between the semesters can be attributed to the differences in the students and TAs within those semesters.

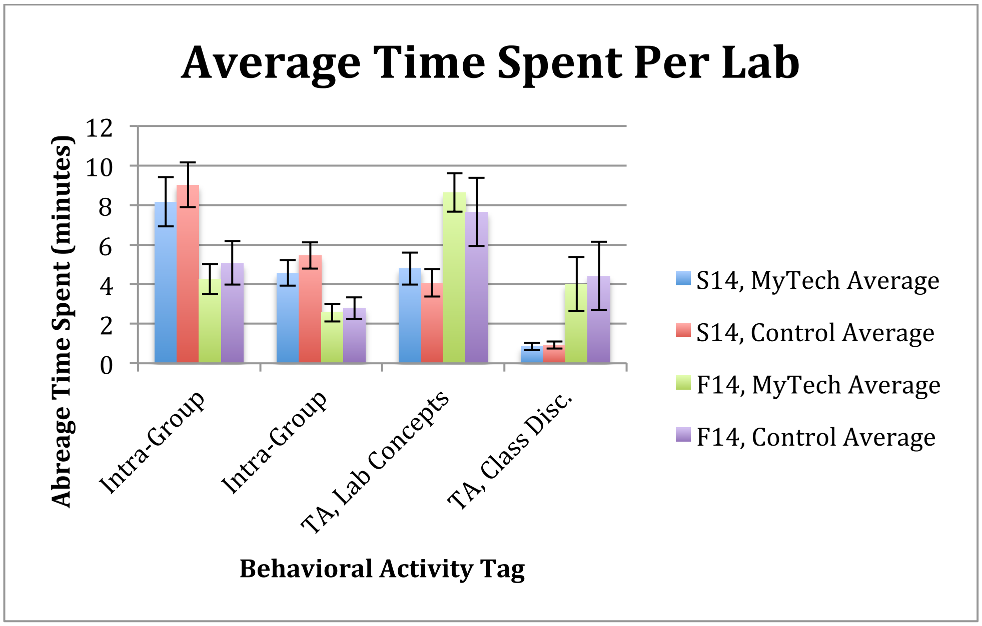


Figure 44 Results from compiling the temporal data over all MyTech and control labs. There are statistically significant differences between semesters in the categories of "intra-group conceptual discussion," "intra-group procedural discussion," "TA lab concepts," and “TA, class discussion.” Error bars represent 95% confidence intervals.

The graph above illustrates differences in the ways that students and TA discussed conceptual and procedural topics between the Spring 2014 ad Fall 2014 semesters. Here, the quantitative data corroborate the in-class observations. The graphs produced by the VOT indicates that the students that worked with the more aloof TA 2 were more likely to discuss concepts with each other than with the TA. Students in the third (Fall 2014) semester, however, spent significantly more time per lab engaging the TA 3 in discussion than those in the second semester. These students were therefore likely less dependent on each other and engaged less frequently in intra-group procedural and conceptual discussions.

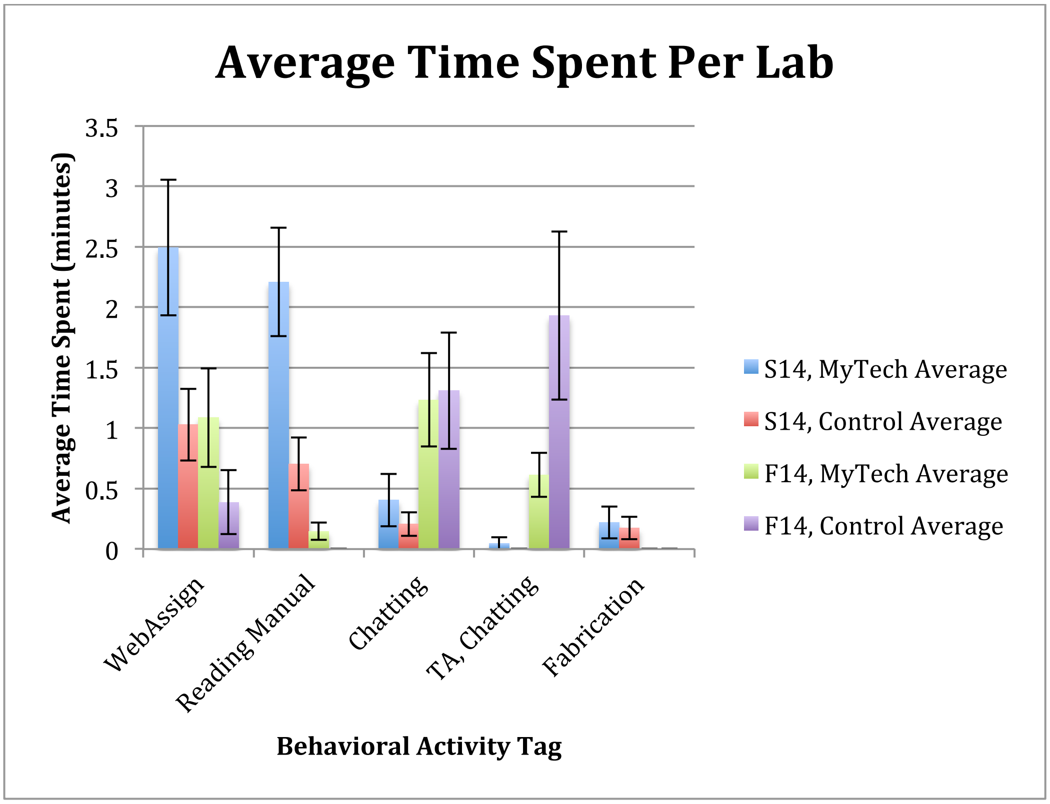


Figure 45 Statistically significant differences between semesters in the categories of "WebAssign," "reading manual," "chatting," "TA, chatting," and "fabrication."

Furthermore, more statistically significant differences were observed under the activity codes, “WebAssign,” “Chatting,” “Reading Manual,” and “TA, Chatting.” The “WebAssign” code is a software tag recorded only when students are scrolling through the lab WebAssignment without any discussion. The results from the WebAssign category are consistent with the differences in TA attitude. Students were more likely to scroll through the WebAssignment seeking answers to their procedural questions than ask the more distant TA in the Spring 2014 semester. The same can be said about the “Reading Manual” category, in which students scrolled through the lab procedure without any discussion more often in Spring 2014.

On the other hand, students in Fall 2014 were much more likely to engage in off-topic conversation with each other and the TA. This is consistent with the suspicion that the TA's constant circling of the room and his desire to participate in students' off-topic conversations led to statistically significant differences between the two semesters.

Fabrication of data only occurred in the Spring 2014 semester. This is likely the result of TA 3's dedication to constant circling of the room and his desire to interact with students. Students likely saw him as more approachable and therefore were more inclined to ask him questions about an issue that they encountered. TA 2's students, in contrast, perhaps felt intimidated or embarrassed about asking the TA a question and thus occasionally fabricated data in order to complete the lab activities. I was eager to see any differences in frequency of fabrication of data between the MyTech and control groups, as it may have indicated students' greater comfort level with one experimental method over the other, but there were no statistically significant differences between the two courses.

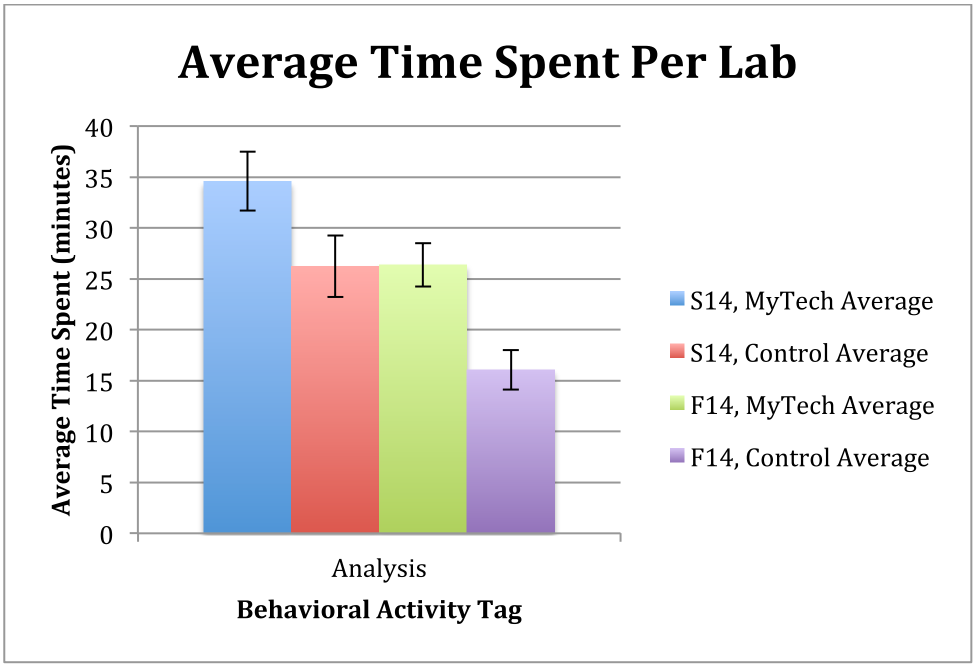


Figure 46 Statistically significant differences between semesters in "analysis" category.

Finally, data from the "analysis" activity tag (which encompassed calculations in DataStudio, Excel, and Tracker) were statistically significantly different between semesters. Again, this behavior is consistent with the qualitative observations made of the two TAs. Spring 2014's TA 2 was more hands-off, and thus students spent more time attempting to analyze data on their own whereas Fall 2014's TA 3 was more hands-on and proactively guided students through their data analysis, thus reducing the amount of time spent in that tag.

The consistency between the qualitative observations and the quantitative data emergent in the videos indicates that the Video Observation Tool protocol is a sensitive measure. This will allow users to determine temporal behavioral student patterns using the VOT in future research.

7.2.3. Positively Technology-Influenced Behaviors

7.2.4.

Generally, we will see that students are obtaining roughly the same skill set from both the MyTech and traditional instructional laboratory curricula. Thus, the less time spent on any particular activity in the lab indicates a higher efficiency. In this section, we investigate the behavioral activity codes that experienced a statistically significant (or nearly statistically significant) positive difference between the control and MyTech sections.

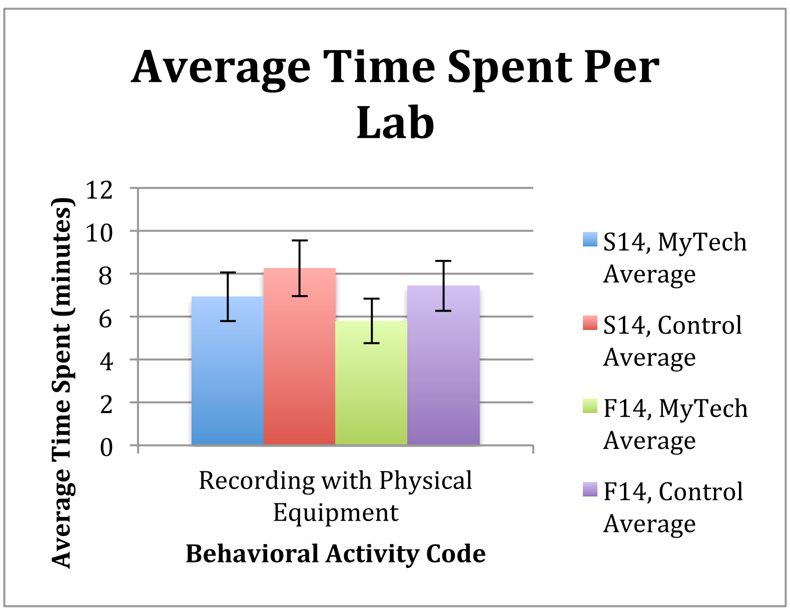


Figure 47 Statistically significant differences between MyTech and control groups in "recording with physical equipment."

The first activity code of interest is the tag that indicates that students are recording with physical equipment. In the study, we have determined that students in the traditional curriculum spend more time recording with physical equipment (meter sticks, stopwatches, calipers, etc.) than their MyTech counterparts. We will discover in the next subsection that this increased time for traditional students is counterbalanced by recording with software for the MyTech students.

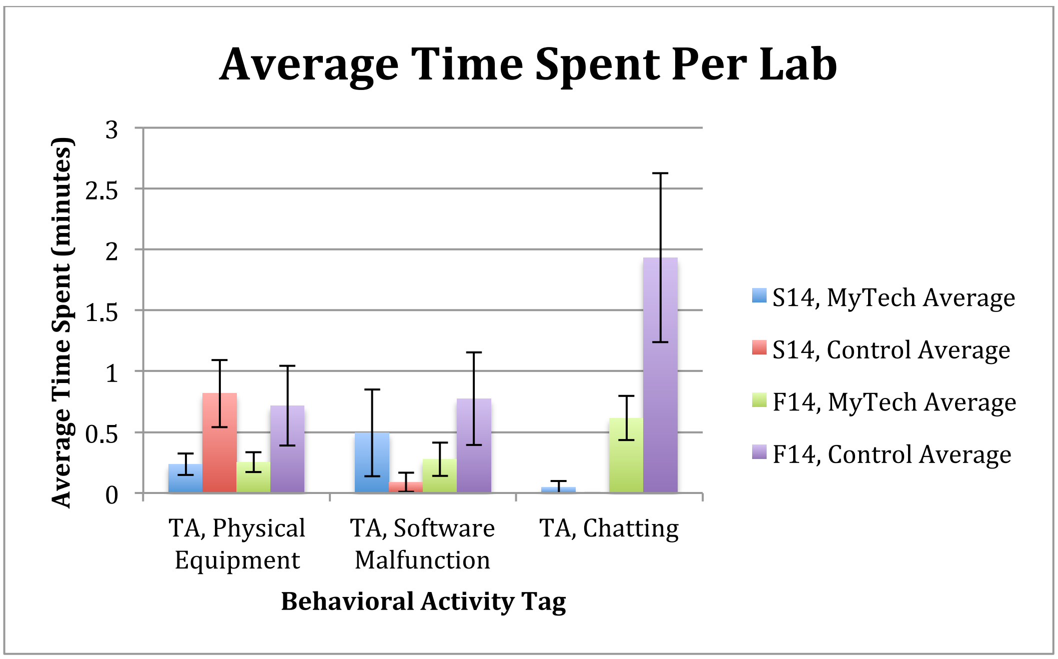


Figure 48 Statistically significant differences between MyTech and control groups in "TA, physical equipment, " "TA, software malfunction," and "TA, chatting."

Furthermore, the MyTech lab appears to cut down on the time spent in some other activity codes, as well. For example, TAs in both semesters spent significantly less time aiding students in the MyTech section with issues involving physical equipment. This is quite surprising, given that the majority of the physical equipment (tracks, carts, balls, calipers, etc.) was common to both the MyTech and traditional curricula. Perhaps MyTech students feel compelled to reserve their questions for trouble-shooting more technical questions.

The code for TAs helping with a software malfunction was a bit more difficult to parse. Students in control section of the Spring 2014 semester needed significantly less time with their TA diagnosing software malfunctions. This might indicate that the more experienced TA 2 was more adept at troubleshooting software issues unique to the control section, such as a malfunctioning DataStudio and/or ScienceWorkshop interface. However, in the Fall 2014 semester, students in the MyTech section needed far less TA time working through malfunctioning software issues than in the control section. This may be due to TA 3’s relative inexperience working with the software and hardware in the control section (DataStudio and ScienceWorkshop interfaces). It also seems to indicate that a less experienced TA will struggle less with solving malfunctioning software issues in MyTech than with the control section. One might expect this result if you consider the relative familiarity people have with their smartphones as opposed to their familiarity with instructional software on the computer.

Finally, students in the control section of the Fall 2014 semester engaged in off-topic discussions with their TA statistically significantly more than they did in the MyTech section. It is not clear if this is a point for or against the MyTech curriculum. One interpretation of these data might be that the students in the traditional curriculum found the equipment easy to use and the lab manual easy to comprehend and thus had more time to engage in off-topic conversation. On the other hand, it could also indicate that students in the MyTech curriculum tend to be more focused on the lab itself and are thus less likely to contribute to conversation with their TA.

Thus, students in the MyTech curriculum spend less time recording data with physical equipment, talking to their TA about physical equipment, and chatting with their TA. The data from the videos indicate that a less experienced TA may have less difficulty troubleshooting the MyTech labs than the traditional labs.

7.2.5. Negatively or Neutrally Technology-Influenced Behaviors

While time in some activities like recording with physical equipment and chatting with the TA is significantly higher for the control section than MyTech, in contrast, there are also several activities in which students spend *more* time in the MyTech curriculum. As we will see, results from the CLASS, TUG-K and adapted CARS are inconclusive in determining a clear distinction between the MyTech and traditional curriculum. We will look to the temporal analyses of both sections to determine if one approach is more time efficient than the other.

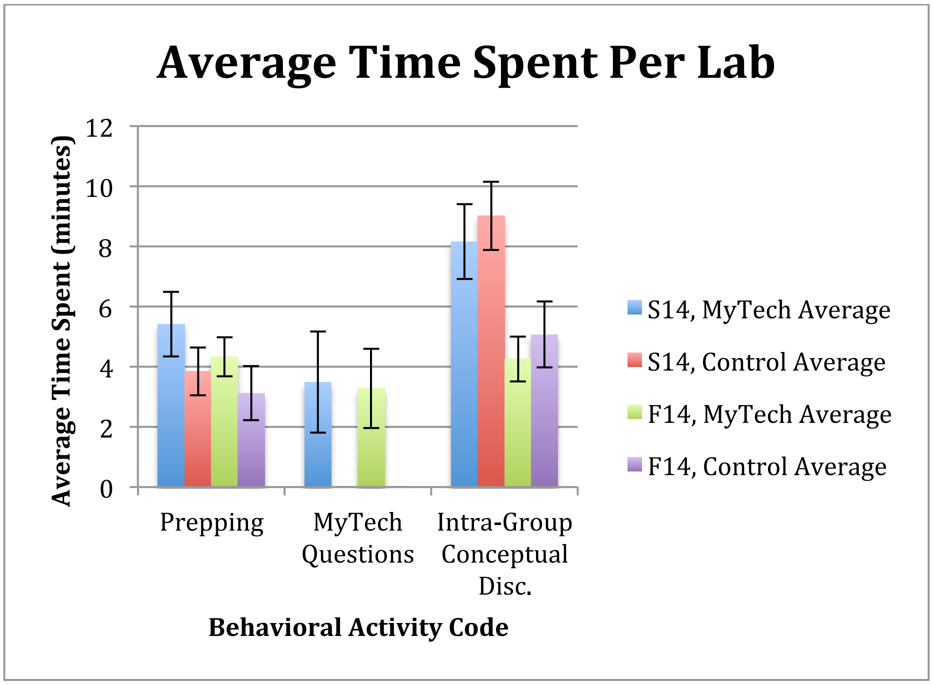


Figure 49 Statistically significant differences between MyTech and control groups in "Prepping," "MyTech Questions," and "Intra-group conceptual discussion."

Students in the MyTech labs spend more time preparing the equipment for data collection than students in the control sections. This would seem to indicate that the smartphone's interface is somewhat less intuitive than DataStudio's for the process of data recording. However, I believe that the higher prep times are primarily the result having of students' re-recording data after having misinterpreted it in Excel. This process often necessitated additional lab setup time. In the future, we could improve the VOT by having it include pure counts of each activity, which would allow us to verify this argument.

The MyTech and traditional curricula differed in two fundamental ways: (1) the equipment used for students' data collection and (2) a series of questions given only to

MyTech students to guide their understanding of the smartphone sensors. In order to compare "apples to apples," a separate activity tag was created for these MyTech questions. There were several additional questions in the first couple of labs in the semester, but they gradually waned in frequency throughout the course of the semester as students gained a deeper understanding of their phone's inner-workings. Thus, students in the MyTech sections devoted roughly three more minutes on average per lab to these questions than did the traditional lab sections. The purpose of these questions was to get students to consider the way smartphones take data so that they might become better at experimental design and troubleshooting, but the results from the "Lab Equipment Survey" (administered only in the third semester of this study) indicated that these additional questions did not aid in students' understanding of the equipment. These questions are likely more appropriate for students in an upper-level physics course in which Einstein's equivalence principle was a topic of discussion.

Additionally, while the differences were not statistically significant, discussion of conceptual ideas within the group were less frequent among the MyTech section. There are two possible interpretations of this: (1) MyTech students are able to more efficiently determine answers to conceptual questions and therefore spend less time talking about them, or (2) MyTech students are not as clear on the conceptual aspects of the lab, and therefore spend less time talking about them.

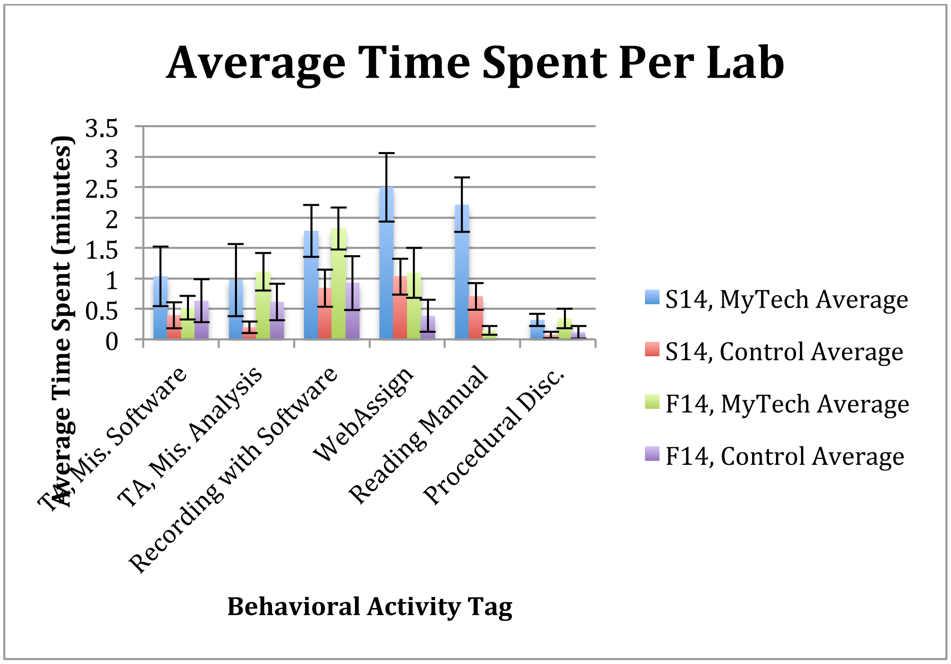


Figure 50 Statistically significant differences between MyTech and control groups in "TA, misunderstanding software," "TA, misunderstanding analysis," "recording with software, " "WebAssign," "reading manual," "procedural discussion."

Despite the efforts made with the first lab and the MyTech conceptual questions sprinkled through the curriculum, students in the MyTech labs tended to struggle more with understanding how to record data with the smartphone and how to analyze it in Excel. This often stemmed from conceptual misunderstandings with the accelerometer mechanism and the coordinate axes fixed to the phone itself. Other issues students encountered in the MyTech curriculum included having difficulty reading the graph inside the app, having trouble reading values for acceleration along the three coordinate axes within the app, figuring out how to change recording rate settings and/or realizing they have too few data points in Excel. The vast majority of these issues were already addressed in the lab manual, but many students overlooked important technical steps (perhaps not understanding their relevance). In addition, neither TA 2 nor TA 3 had any experience with smartphone data collection prior to the semester that they were a TA for the MyTech labs. I attempted to address likely issues with both TAs prior to the lab, but they still struggled to determine the source of the issues and resolve them. Thus, students in the MyTech curriculum (in at least one of the semesters) spent statistically significantly more time in the categories of "TA, Misunderstanding Software" (how to record data), "TA, Misunderstanding Analysis" (how to analyze the smartphone data in Excel or video data in Tracker), "Recording with Software" (which counterbalances the "Recording with Physical Equipment" in an earlier section), "WebAssign" and "Reading Manual" (in which students scroll through the WebAssignment and the lab manual's procedure, usually seeking clues as to how to correct their issues), and "Procedural Discussion" (in which MyTech students spent slightly more time discussing how to record data than their traditional counterparts). The statistical significant difference in "TA, Misunderstanding Analysis" is consistent with the difference in "Analysis" observed in the TA-influenced section. We can again attribute these differences to TA's lack of familiarity with the new equipment and students' difficulties grasping the data collection methods of their smartphones to quickly determine the correct accelerometer axes to graph once in Excel.

7.2.6. A Note about Distractions

Typically, in discussions about this project, someone brings up a concern about the potential for additional distractions in the MyTech class. To address this matter, I created one activity tag ("Playing with Smartphone") dedicated to such distracted exercises. The VOT protocol allowed us to quantitatively compare the average amount of time students in the MyTech and control sections of the course were spending off-task with their smartphones. Indeed, there were no statistically significant differences between the MyTech and control sections.

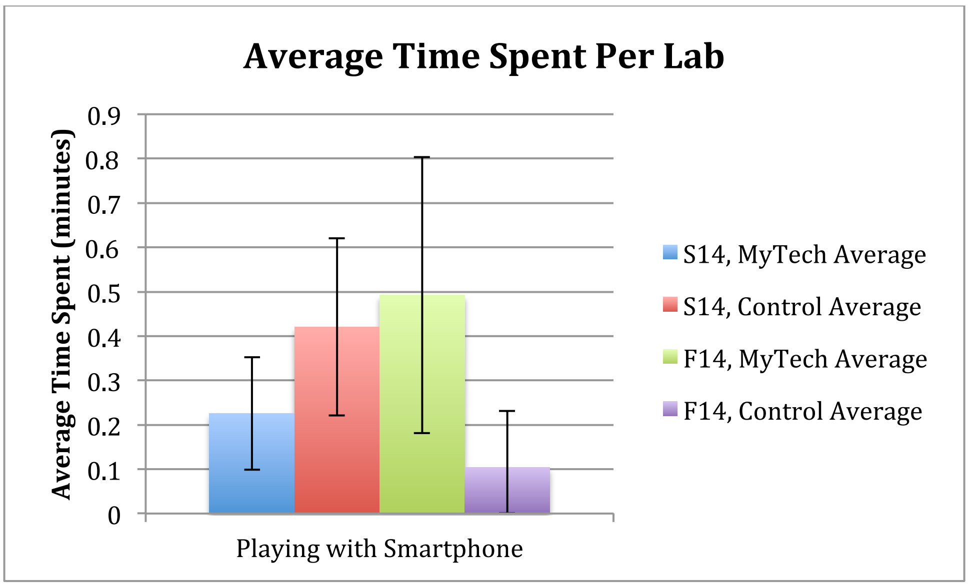


Figure 51 Average time spent on smartphone distractions in the MyTech and Control sections.

Interestingly, neither TA 2 nor TA 3 directly instructed students using their smartphone or computers for off-task activities to stop their behavior. Even for Lab 10 (Macroscopic and Microscopic Springs), a lab in which smartphones are not used, students have been observed playing with their smartphone in the presence of a TA. This would seem to indicate that the students have not been previously reprimanded for such behavior and therefore feel it is acceptable in a physics lab.

Figure 52 A student in the MyTech section plays with his smartphone (during a lab which does not require its use) while in the presence of a TA.

The presence of these distractions, however, is not unique to the smartphone implementation. Students were also observed using both their personal laptops and the laboratory computers to engage in off-task activities, including writing an essay assignment for another class and playing video games.

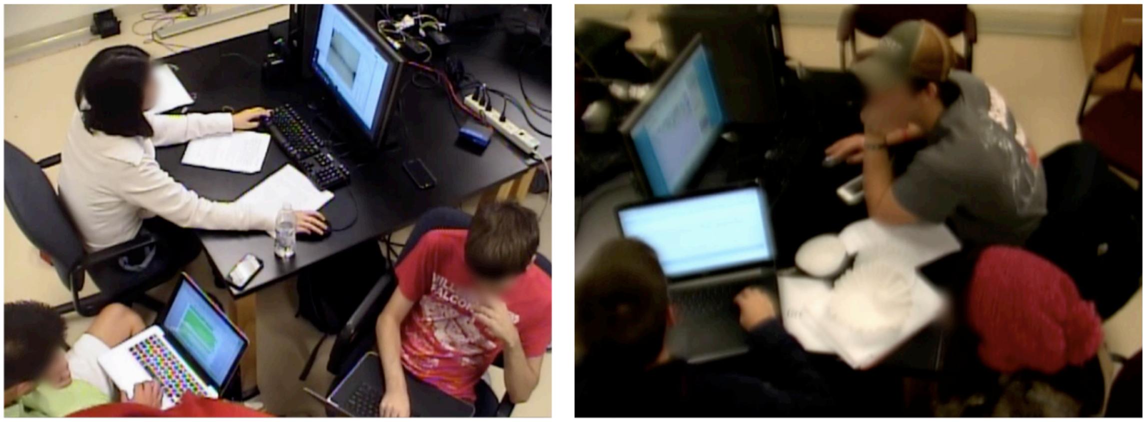


Figure 53 Students can also be distracted by computers. In the image on the left, a student (in the lower-left) works on an essay assignment for another class. In the image on the right, a student uses the lab computer to play a video game during class.

7.2.7. Discussion of Quantitative Video Results

Students in the MyTech curriculum spend more time on their labs. I was able to determine the sensitivity of the Video Observation Tool protocol using anecdotal observations of TA interactions and use the VOT to draw conclusions based on how students spend time in their labs. Unfortunately, on the whole, MyTech students spent more time in activity codes with no significant changes in their kinematics skills or ability to explain how the sensors work. (Their “real world connection” attitudes, however, did improve.) Due to a combination of lack of TA preparation, students skimming the lab manual and possibly unreasonable expectations of students’ ability to understand the process by which the accelerometer records data, MyTech students were more likely to seek out TA help when attempting to collect and analyze data.

7.3. Qualitative Video Analysis

In addition to coding for the purposes of temporal analysis, I also transcribed any potentially meaningful interactions both MyTech and traditional students had with equipment, recording software and analysis software.

The purpose of this section is to demonstrate the strong correlation that exists between students' comments in the labs and the quantitative data obtained with the VOT protocol previously discussed. I will present a few key examples of conversations that took place in the MyTech and traditional labs that emphasize students' attitudes regarding the equipment they were using in the lab.

7.3.1. Lab 1: Discovering the Smartphone Axes/Measurements

Students' emotions in the MyTech section could be primarily characterized by excitement, confusion and wonder (often in that order).

Students generally struggled with the portion of the lab in which they were given an acceleration versus time graph for a bouncing cart (with an accompanying video) and were asked to sketch the corresponding velocity versus time and position versus time graphs.

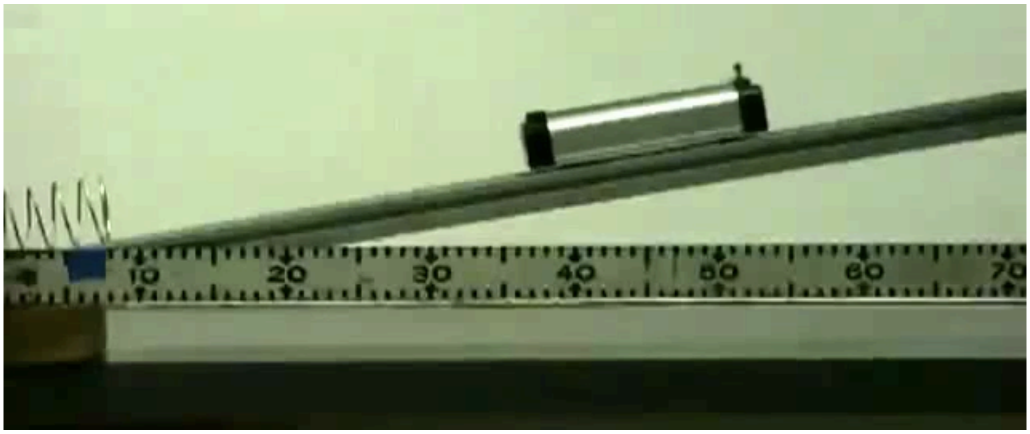


Figure 54 Screenshot of "bouncing cart" video. Courtesy of Tracker software and Douglas Brown.

Students were concerned about how they would be graded on that portion ("We better not be graded super hard on this. This is hard.") and generally spent several minutes on that activity.

Overall, there was excitement during the first lab as students had an opportunity to apply concepts from their physics courses to either their smartphones or the Tracker video analysis:

- **After students figure out how to get the motion graphs in Tracker:**

  "Oh, hey! That's neat!"

- **Upon being asked if the student was excited by this class:**

  "I like how [the researcher] was really excited… I'm not sure why."

- **Upon using the apps for the first time:**

  "Oh, cool! It's like the latitude and longitude! That's so cool!"

- **When the TA checks up on students:**

  TA: "Are you guys doing ok?"

  S3: "Yeah, we're doing alright. We're figuring it out. We're having fun!"

  [S2 looks skeptical.]

  S3 [pointing to S2]: "She's really into it."

  TA: "It's going to be more fun when we get to those later labs. [motions shaking of smartphone in hand]. When we're like knocking the phones around a little bit."

  S3: "We'll use your phone…" [Group laughs.]

  S1: "We can use mine because it's the oldest."

  TA: "We're going to be bouncing it off springs and stuff."

- **Relating Tracker to professional baseball analysis:**

  TA: "So it's just a way we can film something in here, put it in here and get all your nice graphs."

  S2: "Just wondering ... is that like the same program that they use when you're watching a major league baseball game and they show like the pitch"

  TA: "That's a more complicated program, but yeah."

  S2: "More complicated? Oh, ok."

All of the students with smartphones downloaded the appropriate apps and tested them out in the first lab. Throughout the lab, students pointed out some challenges of the apps (such as small graph size, or units of acceleration being in *g*'s) but overall seemed to enjoy the experience.

Figure 55 Students examining their smartphone screens in MyTech lab 1.

In addition, some students were able to acclimate to the way in which the accelerometer took data very quickly and shared that information with their teammates.

- **One student explains his accelerometer values to his teammates:**

  S2: "See like if I hold it like this [in one orientation] I get positive *g* in the *x*-direction but if I hold it like this [rotates 180 degrees], I get negative *g* in the *x*-direction. … If I do this? I should get positive *z*, negative *z*, positive *z*… see? SCIENCE!"

Figure 56 Students determining the smartphone axes in MyTech lab 1.

- **One student attempts to explain to his teammates the accelerometer values:**

  S3: “It says to the nearest multiple of *g*. Ok, so you know how acceleration is in meters per second squared? One *g* is equal to 9.81 meters per second squared.”

  S1: “Right.”

  S3: “That’s what you experience on the surface [of the earth]. So see how this [on smartphone] is showing … what is it? It’s about … 1 *g*, that’s about 0 *g’s*, and then that’s about 0*g*’s?”

  S2: “When you’re holding it straight up, right?”

  S3: “Yeah.” [Seemingly reading off the page] “What is your best guess for the orientation of one of the axes? … I don’t get it. Y is vertical? I guess that’s it.”

Students' excitement over the smartphone apps and Tracker software continued into the second lab two weeks later.

While conversation prospered in the MyTech labs, students in the traditional labs were much more subdued. There was some discussion about how to take measurements using calipers, but beyond that, there were no conversations of note.

7.3.2. Lab 2: Free Fall

Lab 2 is the first lab that requires students in the MyTech section to record data on their smartphones and analyze it in Excel. Meanwhile, students in the traditional lab are simply asked to drop objects and time the fall with a stopwatch. The MyTech process, therefore, is more complicated and the possibility of not correctly recording data (by setting the right recording rate, for example) is quite large. Students in the control sections, by and large, did not struggle with the stopwatch data collection method.

Early on in the lab, students are asked to predict the graphs that their accelerometer will produce when it is in free fall. The graph is somewhat counter-intuitive and, for some, seems to contradict what they've learned in class. One might ask why the software could not have been recalibrated so that it reads -9.8 m/s^2 while in free fall. None of the apps that I could find on the Apple App Store and Google Play Store had the ability to recalibrate the accelerometer with the exception of the PASCO SparkVue app. We considered using SparkVue for this curriculum, but ultimately decided on other apps because SparkVue—as far as I could tell—did not allow the phone's to access the raw gyroscopic data.

- **TA attempts to correct students' accelerometer sketch:**

  S2: "TA Checkpoint. Do we just need to like …?"

  TA: "You're just supposed to show me what you have. So… [looking at sketch of in-flight accelerometer prediction] *this* when it's falling, it's not going to be -9.8. *[break]* It's going to be 0."

  S2: "Why would it be 0 because …"

  TA: "You should test it out and you'll see it. It's in free fall. So you know how astronauts—"

  S2: "So you know how even though the object is moving at -9.8, since it's measuring from the object, it's going to be zero."

  TA: "Yeah, exactly. Astronauts just sort of float around, but they're falling the entire time."

  S2: "Ok. Our picture is bad."

  TA: "And even if you don't believe me, you'll see it when you do the little Excel part."

  [TA exits, and students discuss accelerometer readings]

  S1: "I'm pretty sure that [explanation of the accelerometer prediction] goes against everything we learned in class, though, doesn't it?"

  S2: "Well, it makes sense. Because it's reading like the acceleration *felt* on it. So if it's moving downward with that acceleration, it's not feeling anything. It's feeling weightless."

  S1: "Oh, ok."

- **TA struggles to explain accelerometer sketch:**

S2: "Ok, so gravity is negative… oh wait! No!"

S1: "I don't think it's negative, dude."

S2: "It's accelerating at -9.81 m/s^2 so yeah it's going to be negative, I'm pretty sure."

S3: "But it might not be straight."

S2: "Oh, yeah. It's going to curve until it reaches the max acceleration. This is increasing and then a decreasing jerk and then it hits the ground!"

S3: "Hmmm…."

S2: "Yeah!"

S3: "In my mind .. no, because it's constant acceleration." [TA walks over.]

TA: "Think about astronauts."

S2: "Astronauts?"

TA: "Yeah. So they're falling around the earth in orbit."

S2: "Yeah. They're like, accelerating constantly."

TA: "But they float so…. If they're falling, your phone is falling … they're actually falling exactly the same way except the astronaut is falling around the earth."

S2: "They're accelerating towards the Earth as the Earth … like, yeah."

TA: "So, if they're floating, what does that mean about their acceleration, like, in the *y* direction?"

S2: "Because…"

TA: "You should do the experiment." [TA leaves.]

S2: "Because acceleration – because velocity is a vector so…"

S1: "I think what he told us is that we're wrong."

S3: "Yeah what we did is wrong."

S2: "How is it wrong though? It makes perfect sense! You're accelerating toward the Earth, gaining velocity [motions the falling smartphone], just like astronauts."

S1: "I don't know. Maybe we should just skip this step for right now."

S2: "Wait."

S3 [to emerging TA]: "Can you explain that again?"

S2: "Because an astronaut is also accelerating even though –"

TA: "Well, from his perspective – the sensor is inside that phone. So from our perspective it's accelerating but from the *phone's* perspective—"

S2: "Ohhhhh!! From the *phone's* perspective it's not accelerating. Ok. [TA walks away.] So it's zero I guess."

Many of the MyTech students struggled to determine the axis of interest on the smartphone before collecting their data. Several groups falsely assumed that the axis of interest would be y (instead of z). As a result, these groups correctly recorded data but then encountered issues once they opened the data in Excel. Students in this situation tended to repeatedly take new data, thinking something was wrong with their data recording process. Sometimes, the TAs encouraged them to do so, not realizing that the problem was with the axis that they chose to graph in Excel.

Other students struggled with Excel because they didn't realize until this point that the accelerometer produces data in units of *g*, or that the axis of interest was the *z*-axis:

- **One student explains to his teammates that the units are *g*:**

  S1: "There you go."

  S3: "Dude! That's perfect!"

  S2: "That's terrible!"

  S1: "No, that's actually really good."

  S2: "Negative one? No, because it's going POINT 98." [because it's measuring in terms of *g* units]

  S3: "Alright. Alright well let's just—"

  [TA walks over.] TA: "It depends on how you're holding you phone, so if it's flipped over it might be positive, but then also it's doing it in units of *g*."

  S2: "Ohhhhh, so minus one…"

  S1: "That's when it hits the pillow right? [pointing to graph]

  S2: "No, that's when it's moving. I mean, when it's zero, it's moving. Because it's from the reference frame of the phone. It's like the origin is on the accelerometer. So it thinks it's not moving even though it's falling with *g*."

  S1: "Ohhhh! It is supposed to be -1 g!"

  S2: "Yeah, cuz like the accelerometer is falling with *g*."

  TA: "So that gives you how long [in the air] it will be."

- **TA helps students determine the right axis to graph:**

Figure 57 TA discusses accelerometer theory with students in MyTech lab 1.

S3 [to TA]: “So, see right here [motions to a column] where it changes, like when it increases or decreases?”

TA: “That’s not the right axis.”

S3: “Y? We dropped it like that. [motions how they dropped the phone, see screenshot]”

TA: “That’s [on Excel] like the *y*-axis, isn’t it?”

S3: “I don’t know which is the *y*-axis.”

TA: [motioning to *z*-axis on phone] “This is the *z*.”

S3: “On the phone?”

TA: "On the iPhone, that's the *z*-axis. One way you can check it like to hold your phone in SensorLog and you'll be able to see—like what your acceleration is along the *z*-axis. [S2 holds phone so back is on table surface] See? So as you're holding it like that the *z* is -1?"

S3: "That's even harder."

S1: "So if we wanted *y* are we supposed to drop it like this?" [motions along *y* direction of phone]

TA: "Yeah, if you wanted *y* you have to hold it along—I *think* that's the *y*-axis." [TA leaves.]

S1: "So do we have to do it again or can we just look at—Oh, yeah, just look at the *z*-axis."

S3: "I am *so* confused." [S3 graphs some data—It is unclear if it's correct or not.]

S2: "Oh! It's not stopping!"

S1: "Maybe let's just try it in the *y*-axis again and see the difference."

S3: "But the *y*-axis won't give us the relation better. [laughs]"

S1: "I know."

S3: "The first one was like spot on." [calls TA over]

S3 [pointing to *z*-axis column]: "I don't know where to look on this one and tell where it stops."

TA: "So it's -1, and then… oh man. It looks like—"

S3: "It works with *y* though, because it should, like from our calculation, that should be where it stops, and that's where it goes positive."

TA: "So this is where you're just kind of holding it, right? And this is where it starts dropping, right?"

S3: "Oh ok."

TA: "It's in free fall. It should be zero. It falls down, and then here's where probably where it hit the ground."

S3: "Oh, ok. So that's better. [i.e., there was never a problem with the data.] So can we just graph *those* points, or do we have to graph the whole thing?"

TA: "I mean, it's nice to have a little baseline so get those [motions] and get these [motions] down here."

S3: "Alright. Thank you!"

7.3.3. Lab 3: Uniformly Accelerated Motion

This is the first lab in which students in the control section must use the ScienceWorkshop "black box" interface and the accompanying DataStudio software. In addition, this is the first lab in which students in the MyTech labs are required to record their own experiment on a webcam and then analyze motion from the video in Tracker.

Students in the MyTech lab find the Tracker portion tedious and difficult to complete correctly. The poor quality of the webcams (which make it difficult to differentiate the object of interest on screen from the background due to issues of brightness and time resolution) and confusion over how to save a movie file (as opposed to a "project" file) in Windows Movie Maker contribute to some of the difficulties students encountered in this section. In the end, however, some students are still impressed by the free video analysis software (“Oh, I see! It’s moving! That’s cool.”)

Similarly, students in the control section struggle with their first DataStudio activity. Just as students had difficulty determining the axis of interest on the smartphone, students in the control group are similarly thrown off by the axes of the motion detector:

- **Students have just recorded motion data in DataStudio and are having difficulty interpreting it because of the coordinate system:**

  S1: “Hey [TA]. Is this the one where we put 2 meters? Or do we just put 0?”

  TA: “Yeah, Yeah. It wants you to start at 2. It’s not really explicit about that. It’s like, some people—what was really bad was that some people in my other lab would have this flipped around, so it’d be starting at zero and it would be like ‘you’re wrong.’”

  S3: “Oh so if that’s two meters then it thinks that that’s moving in the $-x$ direction?”

  TA: “Ok, so if this is like your origin [points to sensor on track] so this [on the graph] is like your origin, right here, if this is a graph, so when you move this way [motions on graph], that’s positive. When you move that way, it’s negative.”

  S3: “Oh so that’s $+x$.”

In addition, students struggle with DataStudio’s interface:

- **Students attempt to troubleshoot DataStudio’s inability to record data:**

  S1 [to DataStudio]: “Why aren’t you working? … Maybe this one will work…”

  TA: “What’s going on?”

S1: “We’re trying to hook it up.”

TA: “It should have already been –”

- S1: “Cuz, well, ok. Because we can’t hit ‘start.’ I don’t know if that—”

  TA: “Let me be sure that these are all plugged in.”

  S1: “Try connecting the USB again? Because I used this last year.”

  [TA checks all wires.]

  S2: “Question: Is the power on?”

  S1: “That shouldn’t be an issue. It’s plugged in.”

  S3: “The power is on.”

  TA: “Is this thingy on?”

  S2: “See, I was right!”

  S1: “I mean – it’s still – [not working]”

  TA: “It should. You might need to restart. Just give it a second.” [TA walks away]

  S1: “I am not that patient.” …

  S1: “I guess we’ll just have to do it again.”

  [S2 sighs]

  S1: “So fun, right?” [Clicking.]

  S3: “Yeah, there we go.”

- **Students cannot figure out how to “zoom in” without TA guidance:**

  S2: “Will it let you zoom in or anything?”

  S3: “Uhh… you don’t have trace of it?”

S1: “No.”

S3: “Can you roll over just to see if – ahh. You don’t have a trace of it? That’s really depressing that you don’t have a trace.”

S1: “I’m sure it does.”

S3: “Somewhere.”

S2: “Somewhere.”

S3: “We should just guesstimate.”

[A few seconds later TA wanders over]

TA: “If you guys, like, go to the numbers, like just hover over it, the number itself on the axis—like the squiggle? And you click that and drag that, you can zoom in on your graph.”

S2: “*That’s* what I was talking about!”

S1: “Oh, wow.”

TA: “You can do the same for *x* and *y*.”

Fortunately, students’ issues with DataStudio and Tracker were mediated by the TAs.

7.3.4. Lab 4: Measuring Impulse and Momentum in One Direction

In this lab, students provide an initial push to a cart on a track, and they allow it to collide with a spring. They then compare the force of the spring on the cart to the change in momentum of the cart. The MyTech students record force data using the smartphone’s internal accelerometer and velocity (momentum) data using a webcam with Tracker. Students in the traditional section use sensors plugged into the ScienceWorkshop interface for both force and momentum data.

Students in the MyTech section continue to struggle with the axis of interest and the optimal recording rate for their accelerometers. In both cases, the TA attempts to help but does not directly give students the information they're looking for.

- **Students ask TA for help determining the axis of interest but never directly answers the original question:**

  S2 to TA: "How do we set up our smartphones for this, because we've been trying to do that the entire time?" [no response from TA]

  S2 [reading off sheet]: " 'Use your phone's accelerometer.'"

  S1: "Yeah, it's on that. Yeah, I think it's the *y*-axis, but the numbers are so small…"

  [TA leaves.]

  S2: "We might be able to tell once we send it [to the computer]."

  S1: "Is there any way to change the settings to read in m/s [sic] instead of *g*'s?"

  [TA walks over]

  S1: "Is there any way to change it from *g*'s to m/s [sic] so we can get a decent reading?"

  TA: "I mean, you can always convert."

  S1: "Well, the thing is that it's so small that it's coming out – you can barely even see it on the graph."

  TA: "You may have to go into the settings…"

  S2: "Instead of Hertz would it be seconds?"

TA: "Yeah, you want the record rate in seconds. You want to bump it up to like 60."

S1: "In the recording rate?"

TA: "Maybe like 55."

S2: "Like this?"

TA: "Yeah."

S2: "I mean, I would assume with this that the *x*-axis is going to be the axis of interest."

S1: "But I think it's showing up as *y* though. I don't know why."

TA: "Play around and see if you can't get it into not *g*'s. It might just be that that's just the readout."

S2: "Ok."

[TA leaves.]

S1: "I think it's *y* axis for this one."

S2: "Weird."

S2: "If you look at the graph—"

S1: "Well, the graph – that's the *x*-axis on the graph. Here, come here. [motions toward smartphone on track] You can see it a little bit."

S2: "We might just have to decide after we go forward with it."

S1: "Yeah. I'm pretty sure, because green is the *y*, and if you bounce it [pushes phone into spring] see the green goes all over the place. See and the other ones are reading -1 meter [sic], so I think it's gotta be."

[TA walks over.]

S1: "So I'm assuming *z, x* and *y* [motions in each direction correctly] are the axes."

S2: "Yeah."

TA: "You guys, I don't think [indecipherable]. Remember in the first lab, when you determined the axes? It's basically, when you hold it like this [motions upright] then the *y* is going to read –*g*."

- **TA instructs student to set a "high enough" record rate but doesn't provide specifics; then incorrectly suggests that they set the recording period to 60 s (not something more appropriate, like a recording *rate* of 60 Hz):**

S2 to TA: "What is the *x* direction?"

S3 to S1: "Did you give it to us in an email?"

[Students exchange email addresses]

TA: "Make sure your guys' record rate is set within the phone—that it's, like, high enough."

S3: "Oh, you can change the record rate?"

TA: "Yeah, you can change the record rate."

S1: "I forgot about that."

TA [to class]: "When you guys record to your phones, be sure that your record rate is high enough."

TA [to group]: "It might still be the same since the last time; you just go to settings. And I'd probably switch it to seconds. Bump that up to 60." [Unfortunately, this is not a correct solution to their problem.]

S3: "Alright, we gotta do it again."

- **The same group later on asks TA why there's no data in their file. The TA, not realizing that he set the *period* of recording new data to 60s, suggests that they try recording data with another student's phone. They encounter the same issue, and the student suggests they go back to the Hz setting. TA eventually agrees that this works, but doesn't seem to know why and suggests that they use a very low recording rate (20 Hz).**

S3: "Is today the 26th? How come it's saying that the data file is that small? It's saying it's 0 kilobytes."

TA: "Let me check something…"

S3: "That is exactly what it did to mine."

S2: "Does it have to do with the way that we [indecipherable, motions towards cart]?"

S3: "No, because it would still record *something*."

TA [moves phone around in air]: "Yeah, let's see if we're getting nothing. It says it's recording. Look at this – it says its recording, but the amount of size isn't going up at all."

S3: "That's what I'm saying! That's exactly what it did to me."

S1: "Try sending that."

S3: "Are you sure you can't do seconds? Because it worked when I was in Hertz." [TA silence.]

TA: “You’ll have to switch to Hertz. Why is it-?”

S3: “Does it not work for Hertz either?”

TA: “No, yeah, it’s working for Hertz.”

S3: “Oh, it is? [smiling]”

S1: “We have a problem!”

TA: “I would record in Hertz, then.” TA: “I would just record in Hertz then. Because yeah.”

S1: “Haha, ‘because yeah.’”

TA: “I mean, you’re not getting data the other way!” [TA leaves.]

S1: “Alright. Fourth video is a charm right?” …

TA: “You guys recorded in seconds the last time we did this lab, right?” [false]

S3: “How many Hertz do I do?”

TA: “Do like, twenty.”

S3: “Ok.”

- **The same group later discovers that they do not have enough data points, due to the low recording rate suggested by their TA. The TA agrees to give them full credit until he can sort out what happened.**

S1: “Pshhh. [looking at Excel graph] You can’t even read it.”

TA: “So, yeah, I can at least see—”

S1: “Is that good enough?”

TA: “The problem is that the record rate, being in Hertz, it’s just not going to be as good as being in seconds, but, like, I don't know why it's not recording, you now? Maybe …. Nah, all your guys' data was in seconds. I was like thinking that maybe if you inverted your time axis, or something, that it might like – I don't remember. I mean, I can see your little peak. As long as you guys have that—"

S1: "You know that we know what we're doing."

TA: "I have to look into what's wrong with SensorLab [sic], because there's no reason. I mean, we did this two weeks ago, right?" [TA leaves.]

The TA's incorrect answers to these students' questions could be indicative of his lack of confidence with the vocabulary used by apps in the MyTech curriculum. Additionally, when the TA encounters a group of students that are struggling to obtain the emailed data file, he instructs them to delete their entire account to send the data. While it's unclear what the source of the delayed email is, it is likely not going to be impacted by deleting a student's account from his or her phone.

- **Students have difficulty emailing data to themselves. The email does not appear and the TA suggests deleting the account to send the data:**

  TA: "yeah, like you'll probably have to go in to like settings, and remove your email."

  S3: "Settings, like—"

  TA: "Like, your actual settings, uh, like your actual settings…"

  S3: "Should I, like, change it and send it to my Google email instead?"

  TA: "Uh, it—it didn't work for me, when I was doing it, but the way that I fixed it is I went into the settings in the middle, and then you have to go to your accounts, and I had to like, delete this account."

S3: "How do I delete my account?"

TA: "It's like, you click on 'accounts.' You click on the iCloud, or whatever it is. I had to delete it. And the only thing about that is you might lose some stuff…"

S3: "Like what?"

TA: "Like contacts, or, other things you might have…"

S3 to S2: "Uhhh, do you have an iPhone?"

S2: "[laughs] No." [TA walks away.]

S3: "Man, is this worth the ten bucks [of compensation students were paid for participation in this study]? I don't know anymore…"

S2: "Try your Gmail."

S2: "I mean, we can try other things before you have to sacrifice everything."

S1: "Can't we just like, get the computer science department to, like, make a better app? Like, commission them, like 'we're all working together', right?"

TA: "I don't know if they can do that like *right now.*"

S1: "Just give them to the end of the semester."

TA: "If you guys want to use this phone—"

S1: "Then we'll just like slam it against the screen! [laughs]"

TA: "Alright, I think that's like the best option for you right now."

[S3 resends data file.]

S1: “Hey! I got two emails! So click on this one.”

TA: “Ok, good. You don’t have to delete anything.”

When asked about this “solution” later, the TA suggested that he encountered a similar difficulty with his email—that the anticipated file was never received. He attempted this “solution” on his iPhone 4 and it seemed to fix the problem. This “solution” was never suggested by me or any other researcher.

The students encountered many issues in the MyTech lab 4. While all of the issues were relatively easy to remedy, the TA was ill-equipped and often instructed them to do something at best, unnecessary, and at worst, harmful to the experiment itself. All of the data above were collected from the Fall 2014 with TA 3 because weather complications prevented Lab 4 from happening in the Spring 2014 semester.

The control group in Fall 2014 also experienced many issues but these issues were primarily my fault, as I accidentally provided the TA with motion sensors to collect momentum data instead of the digital photogates intended by the author of the traditional lab manual. In so doing, however, I unintentionally created an interesting situation in which the TA had to set up the motion detectors in DataStudio. The labs did not run as the author had intended them and thus I have not included the transcripts of the lab 4 control group.

Overall, the qualitative results from the MyTech portion of this lab were quite unexpected. I incorrectly expected that, after two labs’ worth of experience recording data on the smartphone accelerometer and analyzing it Excel, students would feel comfortable with the process. Instead, the students and TA alike struggled through this lab.

7.3.5. Lab 5: Uniform Circular Motion

The MyTech and traditional lab manuals for this lab on uniform circular motion are quite similar. The MyTech section has one short additional portion that asks students to determine the angle that the bob's string makes with the horizontal using a webcam and Tracker video software.

Students in the MyTech section, though, had not yet learned the correct recording methods for Tracker. While the instructions explicitly state that the webcam should not be "hand held" (so as to avoid errors that might arise from camera instability), one group disobeys the suggestion:

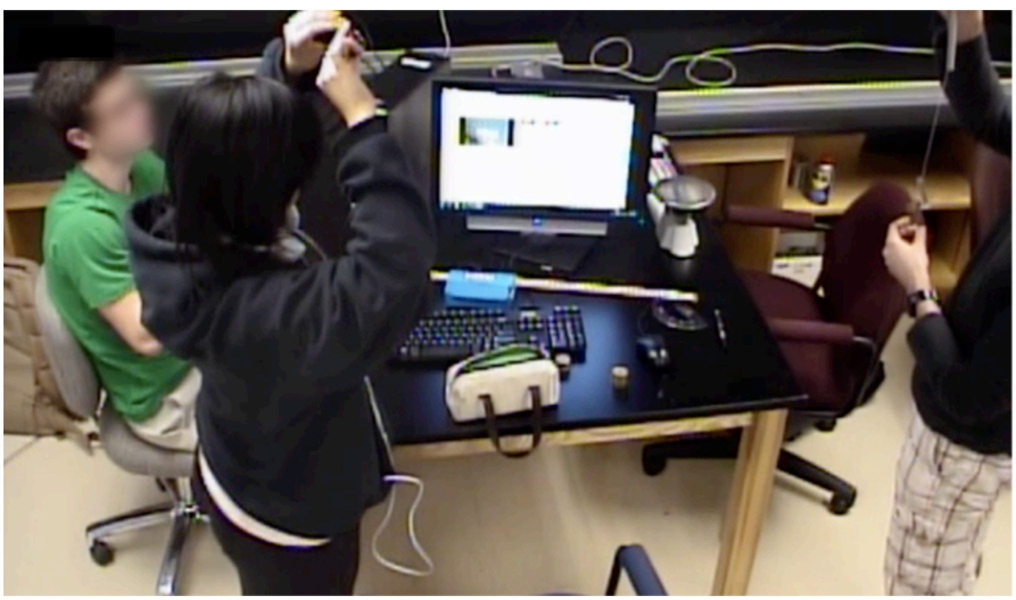


Figure 58 Students in MyTech lab 5 hold webcam to record video of the uniform circular motion apparatus.

MyTech students criticized the webcam's ability to pick up the bob ("It's like a UFO picture,") due to low temporal resolution and quality of CCD. On the other hand, students in the control section also had difficulty making the angle measurement in real-time ("Alright, I *kinda* see where the angle's at."). Furthermore, TA 2, presumably confusing the lab instructions for MyTech and the traditional sections, instructed his traditional lab students to use "the same software that they used before" to find the angle θ, even though no such software has ever been required of them.

In addition, *all* of the students in the *traditional* sections of the lab elected to use their own smartphone's stopwatch features as timing devices to determine the period. This indicates a willingness to take full advantage of these devices whenever possible.

Figure 59 Students in the traditional sections often use their smartphones as stopwatches when appropriate.

Finally, one other note regarding the MyTech labs: several groups used the webcam and Tracker for *all* of their trials (instead of only one, as prescribed in the lab manual). This artificially adds on to the time for a variety of the MyTech students' activity codes.

7.3.6. Lab 6: Impulse, Momentum and Energy

Lab 6 is quite similar to lab 4 in that students in the MyTech section are required to corroborate the data from their smartphone with those from their Tracker video analysis. Students still struggle with determining the axis of interest, or why they even need to record data using both their smartphones and Tracker:

- **Students ask questions of the TA about the axes. The TA interjects with an answer without asking them to really think about it. Some students in the group grasp that the axes on the phone are distinct from the axes *external* to the phone:**

  S2: "Ok. So what? Which axis is this? [looking at the Excel data] And which way did you orient your phone?"

  TA: "It should be y. If you just laid your phone down."

  S1: "The front of my phone was the one that was pointing down."

  S2: "Wait. Do we have to use two axes for this?"

  TA: "No, it's just—"

  S2: "Oh yeah! Because they're separate from each other!"

  TA: "This is lying along the y-axis, so if you lay it like this [motions along track], it's just going to—"

  S2: "We're just finding horizontal acceleration. Gotcha." …

S2: “They call it the *x* acceleration, but it’s the *y* on the phone! [laughs]”

S3: “Dude, what? [laughs]”

- **Students question why both smartphone and Tracker are necessary:**

  S3: “Do we have to record it?”

  S2: “Yeah, with the camera and the smartphone. I’m not sure why though. It seems like we could get all the stuff from either the Tracker software or the phone.”

MyTech students were not the only ones to struggle with this lab. Students in the traditional curriculum also contended with the task of calibrating the force sensor in DataStudio. The students’ actions are only complicated by the fact that many forget to download the appropriate DataStudio file that has already taken into account what sensors are plugged in to the ScienceWorkshop interface.

- **Students didn’t know to open the DataStudio file and thus are forced to configure everything from scratch:**

  S2: [reading off of instructions while looking at the screen] “Click experimental setup. Let’s just try that… where is that? Setup.”

  S1: “Go to setup.”

  S2: “Right there? ... Why don’t they just like *tell* you what to do?”

  [Students have not found saved DataStudio file, and are trying to create it from scratch.]

  [Student starts searching help files in DataStudio]

  S2: “How do we do this?”

  S1: “Ummm… go back to workstation. Go to setup. Add sensor or instrument.”

Both: “Whaa-?”

S1: “Why won’t “add sensor” do anything?”

S2: “[Explicit.] Maybe this [the WebAssign directions] will tell us something.”

- **Students call over TA to help them troubleshoot a malfunctioning DataStudio. TA addresses positioning issues with photogate:**

  S1 to TA: “It recorded the velocity of our first run, but after that, it just stopped working.”

  TA: “Ok so run it right now and just leave it running. … First of all this [touches photogate and moves track to the point nearest the spring without compressing it] you may have moved the track several inches, so this [the photogate] has got to be that … how do I say this … ideally, this is just far enough this way [towards the spring] that it makes a full pass through before it contacts the spring because as soon as you start contacting the spring, you have now introduced another form of loss, which is sort of ‘heating up’ the spring. Anyhow, so … do we see this if we run it? So, I think you’re good now. That’s all.”

- **Students grapple with telling DataStudio to calculate the area under the curve:**

  S2: “What row was that, 2?”

  S1: “Yeah.”

  S2: “[Explitive.] You *thought* that would have worked, right?”

  S1: “Yeah, I thought that would have worked. I guess it’s because you didn’t have the other ones highlighted.”

[S2 Throws hands up in the air (see Figure 60.)]

S2: "It says 'apply to all.'" [S2 starts typing with determination]

S1: "So this would be right with the values here."

S2: [laughs] "Well, we're going to find out. I guess I can do the math in my head. [starts summing values under the curve] … it's gonna be 149/3 …"

S1: "Did you say 149/3? [types into calculator]

S2: "Yeah. 49.6" [types into WebAssign.]

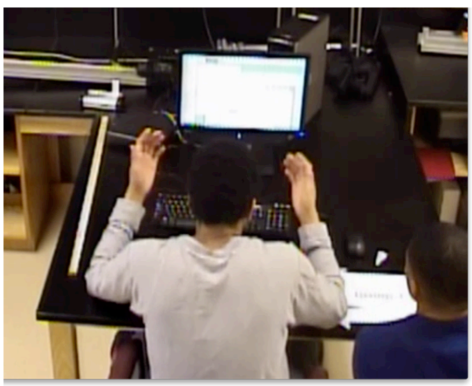


Figure 60 A student in the traditional section struggles in his attempt to use DataStudio to calculate the area under the curve.

Although MyTech and traditional students alike encountered issues in this lab, I believe that those experienced by the MyTech students can be overcome with more rigorous TA training. It is my belief that students in the MyTech lab need to better understand how the data are collected so that they can overcome the barriers associated with choosing the wrong axis to graph or questioning why Tracker and smartphone data are both necessary. Overcoming the issues with the traditional lab in DataStudio, however, is more difficult to achieve only with additional TA training. The issues there are widespread throughout the program itself.

7.3.7. Lab 7: Simple Harmonic Motion

In this lab, MyTech students and traditional students are required to find Hooke's constant for a spring, determine *g* from the period of a spring pendulum and determine *g* from the period of a simple pendulum. In addition, MyTech students were also required to find *g* from the period of a physical pendulum, using their smartphone as the "bob."

For the most part, neither section struggled with the first three portions of the lab. MyTech students, however, were challenged by the physical pendulum portion of the lab. This is likely the result of one common error. At this point, let us diverge from students' comments about the lab to discuss some of the lab's technical intricacies.

Consider the graph below, created by attaching the smartphone to the bottom edge of the physical pendulum apparatus.

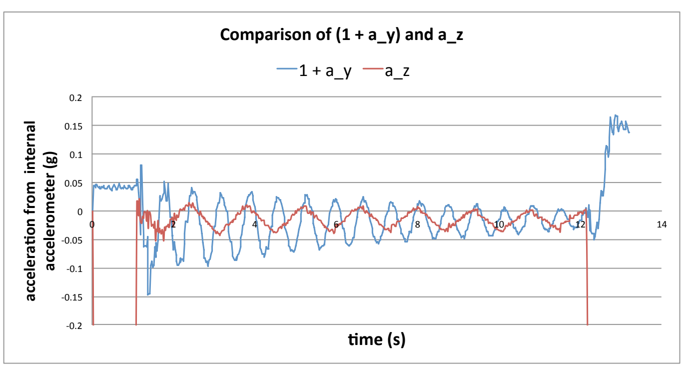


Figure 61 A comparison of data detected by the y- and z-components of the accelerometer in a physical pendulum lab.

I intended for students to consider the motion along the z-axis of the accelerometer in order to determine the period of the physical pendulum. Instead, several groups looked to the y-axis of the accelerometer. In doing so, they obtained a period roughly half of what is expected. To understand this difficulty, consider the motion of the smartphone as it swings back and forth through some angle, θ. Unlike in traditional coordinate systems for evaluating centripetal force, consider the acceleration experienced by the smartphone, and thus use a coordinate system fixed to the phone so that the y-coordinate will always point radially inward (toward the axis of rotation). In this way, the y-acceleration experienced by the smartphone will be zero at the extremes and a maximum at its lowest point. Thus, through each cycle of the physical pendulum, the smartphone will pass through a point of maximal y-acceleration twice, thus producing two maxima.

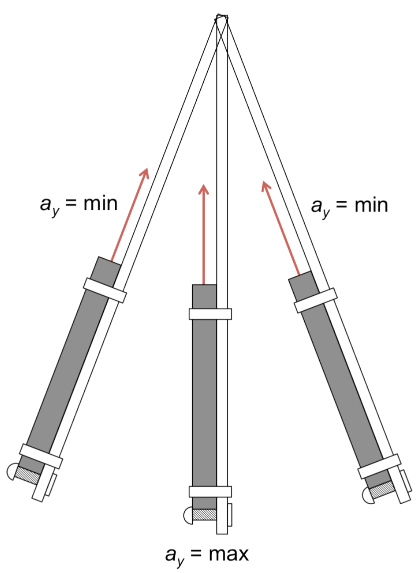
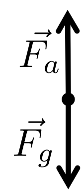


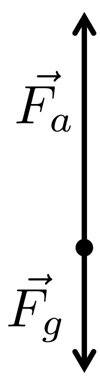
Figure 62 A schematic of the physical pendulum apparatus which uses the smartphone as a bob.

Additionally, one can examine why the a_y data oscillate around a point just below $-g$. First, recall that the reading on an accelerometer is proportional to the negative of some force, F_a. For example, when the phone is stationary, the phone's accelerometer displays a_y, as shown in the figure below:



$$a_y = -g = -\frac{F_a}{m}$$

In the same way, one can determine the a_y experienced by the smartphone at the bottom of the pendulum's arc:



$$F_a - F_g = \frac{mv^2}{r}$$

$$F_a = F_g + \frac{mv^2}{r}$$

$$a_y = -\frac{F_a}{m} = -\frac{1}{m}\left(F_g + \frac{mv^2}{r}\right)$$

$$a_y = -g - \frac{v^2}{r}$$

Thus, the a_y value displayed on the app will be ${v^2}/{r}$ below $-g$. Furthermore, since $v \propto \sin \omega t$, and $a_y = -g - \frac{v^2}{r}$, the graph of a_y has the same shape as $\sin^2 \omega t$, but is shifted.

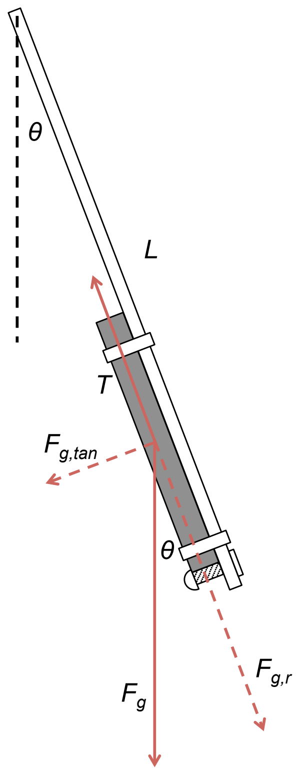


Figure 63 Forces on pendulum bob (smartphone) at one arbitrary instant of the pendulum's period.

If an instructor is planning to use this experiment in their lab, he or she might also want to consider creating a VPython simulation of the pendulum's movement with the possibility of adding the acceleration vectors. To do this, we must determine the tangential acceleration, a_t, and the radial acceleration, a_r. Let us first determine an expression for a_t by examining the restoring force, $F_{g,t}$, the tangential component of the force due to gravity. In this case,

$$F_{g,t} = -mg\sin\theta = ma_t = m\alpha L = m\ddot{\theta}L.$$

Then, we can solve for $a_t = -g\sin\theta$. Similarly, we can sum the forces in the radial direction (the tension force, T, and the radial component of the force due to gravity, $F_{g,r}$) and set it equal to $\frac{mv_t^2}{L}$:

$$T - F_{g,r} = \frac{mv_t^2}{L},$$

$$T = ma_r = m\left(g\cos\theta + \frac{v_t^2}{L}\right).$$

So $a_r = g\cos\theta + \frac{v_t^2}{L}$. We can then use these quantities to graph a_t and a_r in VPython. The code for the program can be found in Appendix E. (The code was adapted from a basic pendulum code (Harrison, 2008) to include graphs of the radial and tangential components for acceleration.)

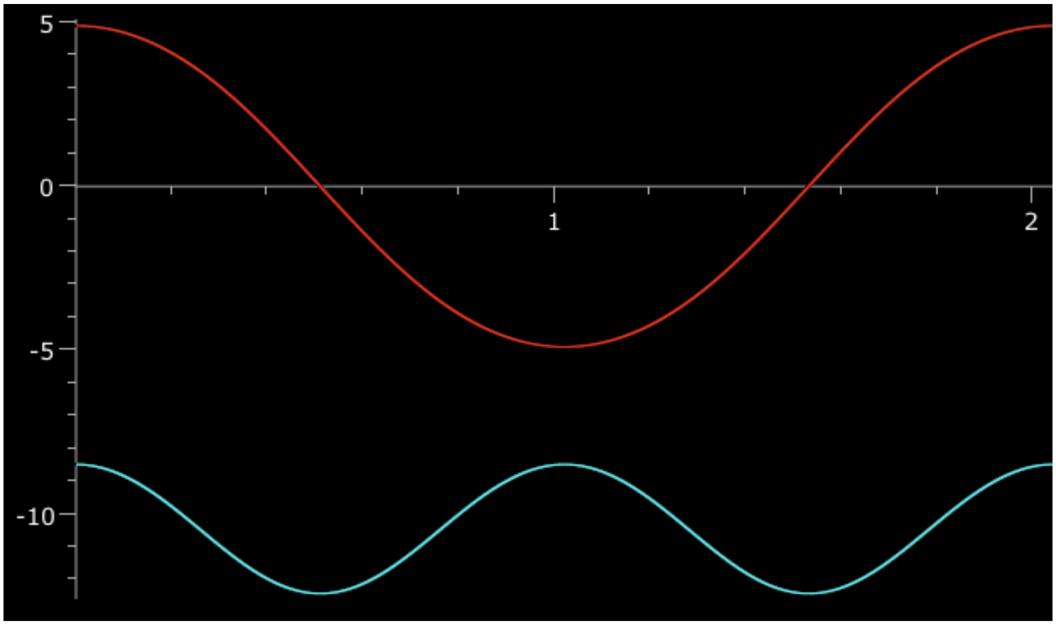


Figure 64 VPython simulation of a_t (red) and a_r (cyan) for the pendulum problem. The horizontal axis is time. The parameters in the program differ slightly from the experimental parameters, and thus the amplitudes from the simulation do not exactly match those found in the experiment. The general shape and relative frequencies of the graph are similar to those found in experiment.

In Fall 2014, several groups in this lab encountered this difficulty with a period off by a factor of two, but neither the students nor the TA recognized the issue. In fact, TA 3 stated to one group "It seems like everyone is getting half [the period that they expect]." A similar issue was encountered in Spring 2014 by TA 2, and he was able to come up with some reasoning:

- **Students get half the period they expect. TA helps them figure out why.**

  S1: "We did it once using the tops of the peaks, and once using the bottom of the peaks, and we got really different answers."

  S2: "And both were wrong [for the period of the pendulum]."

TA: “I would be very comfortable using this, this, this, this and this [pointing to areas on the graph].”

S1: “I think that’s what we did. We needed five, so I think we started here.”

TA: “But… is this like milliseconds”

S1: “Yes, this is milliseconds.”

TA: “So if that’s the case, ….[long pause]….ok so we need to take a step back and decide what is this data telling us, or you can just tell me if you know. What is this data telling you? This isn’t a trick question. What does this data mean?”

S1: “It’s showing us the …uh… [motions back and forth like a pendulum with his hand] the acceleration in the x-direction at certain points and, since it oscillates, it’s changing [motions again].”

TA: “So where is the pendulum when …”

S2: “It would be at the center. Because it’s accelerating fastest, so we need it at x = 0? Or something?”

TA: “Well, so, from center to center is fine. You know what I mean? … I guess what I’m getting at is, I didn’t sit hear and watch you do your experiment but from here to here is not so different … than from here to here. *This one* is a little bit odd, but maybe actually this one is a peak, and that’s a peak and *that’s* a peak?.. There is some discrepancy there. What sticks out to me most is … well… uhh… I don’t know, I think I would have bought it. 0.75 s, I know it’s different because there’s not a weight on it. How big was your angle when you started it?”

S2: [unintelligible]

TA: "Uh huh. I mean, I know it's different cuz there's not a mass on it [is over at pendulum now, letting it swing back and forth] but … so like from here to where it gets back to this point, ya know I'm just seeing if it seems reasonable. Yeah, I mean, it seems *reasonable*. It's less than a second, but I don't know if I'd call it half a second … mmmm…."

S2: "Our first answer was …."

TA [to another group]: "What did you get for the period of your physical pendulum?" …

Other group: "1.23."

TA: "Yeah, man, I dunno. I would have thought 0.7 or 0.9 was a reasonable answer. Let me look at what it's looking for. I'm probably going to tell you that your answer is ok. I know you understand the method. I don't think physically it's actually taking a whole second… [long pause] … Oh! I think I know what the problem is. I think. Ummm… [long pause] Let's just watch this for a second. Don't worry about trying to figure anything out necessarily. And just pay attention … to now, alright, what's a period? A period is here [holds the pendulum towards himself], … [then swing it all the way back] and here [holding the pendulum again toward himself]. And I missed this to the first time that I looked at your data. Maybe you've already accounted for this. How many times does it go through the center per period?"

S1: "Twice."

TA: "Right. So did you account for that when you were looking at those peaks? Has it clicked yet?”

S2: “We need […] to divide by two?”

TA: “And yeah, that’s a subtle different, count a full period, it’s hitting that peak twice. And that’s one [motions a full pendulum swing], that’s two [motions again]. I missed it too.”

Thus, TA 2 was able to determine reasoning for the period being half of what they expected. The physical pendulum portion of this lab was an interesting exploration into how accurate the phones themselves can be. However, those that did not choose the intended axis ran into a complicated, unanticipated problem that even the TAs struggled with. This ambiguity in axis choice will be removed in future MyTech labs.

7.3.8. Lab 8: Conservation of Mechanical Energy

In this lab, students in the MyTech and traditional curriculum are required to determine the final exit speed of the ball at the bottom of the ramp. The MyTech students were additionally asked to verify this speed using a webcam and Tracker.

The only real questions asked of the TA during the Tracker portion involved the positioning of the camera and the determination of the frames to analyze in Tracker. Some students were unclear as to how, exactly, they should determine that final speed.

- **A substitute TA in Spring 2014 suggested students are more interested in the motion on the ramp than the motion after the ball has left the ramp, but seems unsure:**

  S2: [for Tracker portion] “Does it want us to have the camera pointed from here to here [top to bottom of ramp], or from here to here [bottom of ramp to floor].”

TA: "That's kind of interesting, because, well first of all, I agree with you asking me this question since it is not clear whether they want us to use the motion before or after the fact. So, I believe what they want you to do is position it as you have it, so that you can see the track, the meter stick [with one end on the floor and the other above the table] and there should be a change in x and a change in y in the Tracker software and we can associate it with the motion along this track and I believe that."

S2: "The only thing I can tell is it says, 'as it leaves the track' and that's what we're trying to find which makes me think that we go from here to here [top to bottom of ramp]."

TA: "Yeah… because I'm trying to think if you were recording it down here [bottom of ramp to floor] I don't think .. I think it would be quite difficult to use this data [motions between bottom of ramp and floor] this visual data to calculate the speed here [bottom of ramp]. I'm going to try to think about that question and confirm it, but go ahead and start."

In another case the following semester, a group recognized that they have only three frames with which they can analyze the motion of the ball in Tracker, and thus are forced to re-record and analyze the data. Overall, however, students' Tracker data were consistent with the data from the other portions of the lab.

7.3.9. Lab 9: Angular Impulse and Angular Momentum Change

For the first time, students in the MyTech section were asked to record *gyroscope* data (as opposed to *accelerometer* data). Some students struggled to determine the axis of interest (which is admittedly more complicated in gyroscope mode, as students must correctly apply the "right-hand rule"). Still, there was an overwhelming sense of wonder regarding the smoothness of the data collected ("Woah. Look at how smooth that [data] is,"):

- **Student is amazed by how well his phone recorded the angular velocity data:**

  TA: "What direction is the angular velocity going to be in [on the smartphone]?"

  S1: "Depends on which part of the graph you take."

  TA: "Well, it looks like—"

  S2: "It looks like it's going to be the gyroscope, so it would be the—"

  TA: "Yeah, you want the gyroscope data."

  S2: "Along the –"

  TA: "Along what axis?"

  S2: "The *z*."

  TA: "Because this is your *x* [motions along *x*], this is your *y* [motions along *y*], so *r* cross *F* is up."

  S1: "OK. But wouldn't it depend on which direction it's spinning, too? Or no?"

  TA: "Yeah, it will. So, in one way it's going up, the other way it's going down, but it's along the *z*-axis."

  S1: "Ok. That's all that matters?"

  TA: "That will determine the slope. Ok, so see right here [motions towards Excel graph]?"

  S1: "Yeah."

TA: “So, yeah, it determines the slope that you have.”

S1: “Yeah, I could see like the same thing happening as I was just like playing with mine [smartphone] on here. It was pretty cool. Like, that little graph. I was surprised by how smooth it was.”

TA: “Yeah, there are *good* gyroscopes in here.”

S2: “Yeah, that’s because your gyroscope is used for like, lots and lots and all sorts of functions. [waves smartphone around in air]. Wait, so is this the right graph we need?”

[S2 takes control of computer mouse.]

TA: “Yes, yes. Very nice.”

S1 [still playing with smartphone on turntable]: “I mean, but even graphing it on the phone turned out, like, really well.”

TA: “Yeah.”

Figure 65 Student in the MyTech section is impressed by the smoothness of the data produced by his smartphone's gyroscope.

Still, complications emanating from the right-hand rule and students' continued disorientation over the smartphone's axes cause confusion in the MyTech labs.

- **Students are confused by the seeming inconsistencies between the smartphone's fixed axes and the axes provided in the lab manual (for both sections):**

  S2 [reading off of instructions]: "Plot an angular velocity versus time graph. [looking back at Excel.] Ughh. I don't know which one that is." … "I think it might be this one … but I'm not sure. Everything else is like all negative, this one is the only one that's changing."

  [S1 motions the three axes on the phone with his hands, then mimics the phone rotating in the *x*-*y* plane.]

S1: “I think that’s right because [motions in the *z*-direction] this is the *z*-axis and it’s spinning around it. [mimics phone rotating]”

S3: [pointing to directions, presumably to the figure below] “No, but here, it says the *y* is up.”

S1: “Oh, it is?”

S3: “Yeah.” [giving S1 the instructions]

S1: “Oh.”

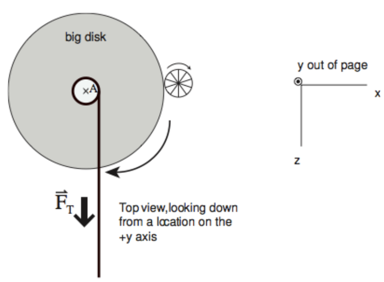


Figure 66 A "bird's eye view" perspective of the angular momentum apparatus collecting data from the traditional lab manual.

- **TA describes the smartphone-fixed axes to students:**

TA: “Are you guys getting your data yet?”

S3: “Yep.”

TA: “Awesome.” [Students open data in Excel]

S2: “So how do we transfer all this over?”

TA: “So you just want the gyroscope data in the *z*-axis.”

S2: “So … that’s ‘rotationZ?’ or *y*?”

TA: “Yeah, but in the traditional lab, they consider [motions on turntable], like, this to be *x* and this to be *z*, but your phone – [motions on smartphone] this is *x* and this is *y*. So let’s say it’s in the *z* direction.”

While none of the traditional lab students encountered any difficulties obtaining and graphing their data, students in the MyTech lab were visibly and audibly excited by the prospect of recording rotational motion data with their smartphones.

7.3.10. Lab 10: Macroscopic and Microscopic Springs (Young’s Modulus)

This is the only lab in the traditional mechanics curriculum to which no changes were made in the MyTech curriculum. There were, as expected, no differences in students’ comments with regards to the lab equipment.

7.3.11. Lab 11: Speed Dependence of the Air Resistance Force

In this lab, the MyTech and traditional students must attempt to determine the terminal velocity of a series of coffee filters using a stopwatch and a meter stick. In addition to the stopwatch method, the MyTech students were also asked to determine the terminal velocity using Tracker. The instructions for the Tracker portion of the lab were purposefully scant. This led to some student questions regarding the webcam quality, the importance of camera positioning and placing the coordinate axes in Tracker.

- **Students review the video of the coffee filters falling and discuss methods they can implement to increase the quality of the video.**

S2: “Wow, that’s really… [laughs]” [possibly blurry?]

S3: “Nice…”

S2: “Oh we have to add a calibration stick and coordinate … first. You can *barely* see the filter. [clicks] I can’t… [laughs] … and then [clicking] calibration stick … and […] Maybe we need to do a smaller step size.”

S3: “Try to do it again against a darker background [to increase the contrast between the white filters and the background]” [S3 clicks to start tracking the filter]

S2: “But isn’t that the shadow? Isn’t it [the coffee filter itself] up there right now? [points above camera’s view on screen] I have no clue.”

S3: “I’m just going to do the bottom of the shadow-looking-thing.”

S2: “I don’t know if that’s right.”

S3: “Oh. [clicking]”

S2 [pointing to screen, then throwing hands up] “It’s so white against the background!”

S1: “Yeah, you can’t …”

S2: “You can’t even see it.”

S1: “Should we do it [record another video trial] against that? [points to dark cabinet in room]”

S2: “I guess… [to S3, who is still clicking in Tracker] Let’s try it against the cabinet so we can tell the *difference*.”

- **Students discuss the camera positioning and the effect of perspective on their data.**

  S2: “Maybe we should do it from the ground because that is supposed to be level with that, you know? [points to two places on screen] Like—"

S3: "What do you mean?"

S2: "Like record from the ground so that you can this and this [points to screen – perhaps at meter stick] on the same level, because we're recording on the table and the perspective is different."

S1: "Yeah, but if you record from the ground, though, like, all the points at the top would be like closer together."

S3: "Yeah. I think … I think this will do, I think. We'll just go… [click]"

S2: "Or you can [clicks], but then, won't it be shifted down a little bit? … [long pause] … Well, let's find the average velocity and if it doesn't look right then we can do it again."

- **Students determine that the positioning of the axes won't make a difference on the reported speed of the falling coffee filters.**

S3: "Yeah, so like this is the x and that's the why [motions toward screen]. Is this what we need? … Do you think…?"

S2: "Or do we put it [the origin] at the bottom and say that it [the coffee filter] is coming down to it? I don't know."

S1: "Wouldn't we want … like …"

S3: "Either way it's going to be the same velocity."

S2: "Yeah."

By the end of the semester, the majority of students have become more comfortable with Tracker and are able to analyze movie files with greater autonomy than they could earlier on in the semester.

8. Results from Pre- and Post-Semester Testing

Section 5.6 on "Evaluation Measures" discusses a battery of pre- and post-semester tests given to students in both the MyTech and Control sections. The TUG-K (Test of Understanding Graphs in Kinematics), CLASS (Colorado Learning Attitudes about Science Survey), and the adapted CARS (Computer Anxiety Rating Scale) were among those given to students before their first and last labs of the semester. As a means of collecting more data about the way students directly interact with their equipment, in the Fall 2014 semester, I also administered a Lab Equipment Survey to both sections and a Smartphone App Survey to the MyTech section. While some results are interesting in their own right, we are primarily interested in comparing the response shifts in the MyTech and control sections from the beginning to the end of the semester.

8.1. TUG-K Results

Many researchers have asked about how the MyTech curriculum impacts students' abilities to read graphs. The question arises out of a concern that smartphone accelerometers provide students with acceleration versus time data. At the surface, this appears troubling because students in the traditional curriculum are not typically asked to analyze the motion of an object based directly on acceleration versus time graphs. In fact, most students in the traditional curriculum will never even encounter one! Acceleration curves can be difficult for students to interpret, and so people question how this additional exposure to accelerometer curves might impact MyTech students' abilities with graphs in kinematics.

Before addressing the data, consider how the acceleration graphs were used in the MyTech lab curriculum. At the outset of the creation of the MyTech curriculum, smartphones were the *sole* data collection devices. That is, the first series of MyTech labs did not use webcams or Tracker. Thus, at the beginning, considerable thought was put into how students would be able to gain information about lower-order physical quantities like position and velocity from a high-order physical quantity like acceleration. Unfortunately, due to drift in the accelerometer, we could not rely on accurate values for velocity and position by simply integrating (or find the area under) the acceleration curve[100]. Therefore, I looked to more accurate and reliable methods for measuring velocity, like Tracker. With correct positioning of the webcam, one is able to obtain much more accurate results for velocity (and momentum).

In the traditional labs, students use DataStudio, motion detectors and photogates to measure position and velocity, respectively, and often compare these values to those obtained by the spring force sensor. Students in the MyTech curriculum, on the other hand, use Tracker to measure position and velocity and use the smartphone accelerometer to (indirectly) measure force. A table summarizing these data collection techniques is given below. Note that the asterisk in the table indicates any lab technique that MyTech students were required to use, but traditional students were not. (For example, lab 10 on air resistance required MyTech students to check their coffee filters' terminal velocities using Tracker. In cases such as these, an effort was made to reduce slightly the number of trials using traditional methods to ensure roughly the same time would be required of MyTech and traditional students.)

Table 11 Physical concepts and the methods used to detect their changes

	position, *x*	**velocity, *v***	**acceleration, *a***	**force, *F***	**angular velocity, *ω***
Traditional	motion detector	photogate		spring force sensor	angular photogate (indirectly, $v_{tan} = R\omega$)
MyTech	Tracker	Tracker	smartphone accelerometer	smartphone accelerometer (indirectly, $F = ma$)	smartphone gyroscope
Labs in Which Technique Was Used	1*, 3, 5	1*, 3, 4, 6, 8*, 10*	1*, 2*, 7*	4, 6	9

Due to these changes, we investigated the impact of students' kinematics graph skills. To do this, we again made use of the "normalized gain."

The table below summarizes our findings, where the number following the "±" indicates a 95% confidence interval:

Table 12 Results from TUG-K

	MyTech	**Traditional**
N	30	27
Pre-Test Average	65%	69%
Post-Test Average	74%	78%
Normalized Gain	0.244 ± 0.240	0.270 ± 0.280

There is no statistically significant difference between the gain in kinematics skill sets between students in the MyTech and traditional sections. A power analysis suggests that one would need $n = 108$ students to attain a statistically significant gain ($p < 0.05$) in the MyTech section and $n = 133$ students to attain a statistically significant gain ($p < 0.05$) in the traditional section. To obtain more insight into the distribution of normalized gains, one can examine a histogram of normalized gain. Instead of pure counts of the normalized gain, we consider the fraction of respondents in each section whose normalized gain fell within a given range of normalized gains, as shown in Figure 67.

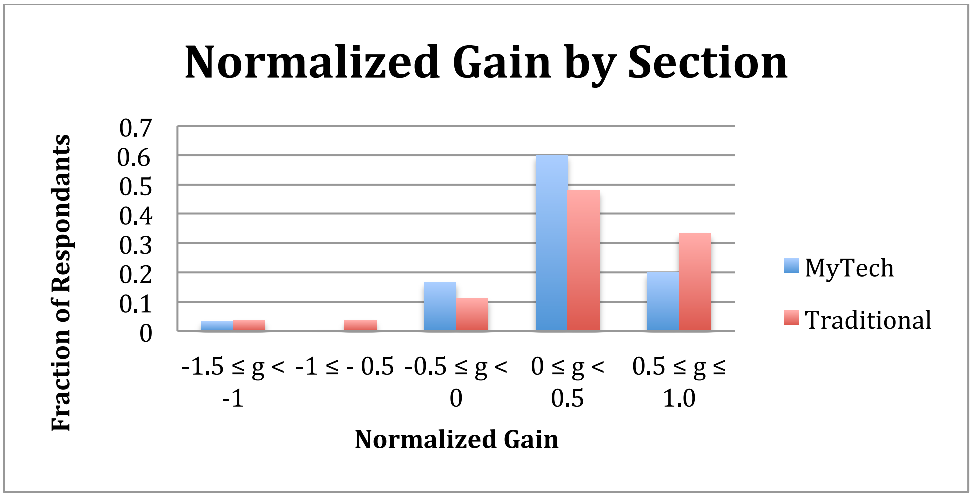


Figure 67 A comparison of the normalized gain in TUG-K scores between the MyTech and traditional sections.

In the MyTech section, fewer students attained high gains ($0.5 \leq g < 1.0$) and slightly fewer MyTech students experienced a positive shift in their kinematics graph skills (80% in the MyTech section to 81.5% in the control section.) One may notice the absence of error bars in Figure 67 above. This is because the figure is essentially a frequency histogram – normalized only by total count of MyTech (n = 30) and traditional (n = 28) TUG-K respondents. Once could have found the average count of respondents over the course of the three semesters and reported a confidence interval by semester, but the sample size per semester is so low as to eliminate nearly all meaning from that interval. We can consider expanding this study to include a greater sample size in future work.

While these differences are not statistically significant, future implementations of MyTech-like lab curricula may want to consider the potentially negative impact that they have on students' kinematics skills. Future lab curricula may want to consider removing the labs that focus on students' abilities to read accelerometer graphs directly (labs 1, 2, and 7) and instead use the accelerometer in students' smartphones as a means of calculating the force experienced by phone (such as in labs 4 and 6).

8.2. Adapted CARS Results

In order to determine students' technological anxiety, the Computer Anxiety Rating Scale was also administered to students at the beginning and end of the semester. First, consider how the Adapted CARS was analyzed. Recall that the Adapted CARS contains a series 18 statements, and students respond with a five-point Likert scale to what degree they agree with statement. Nine of these statements (items 2, 4, 5, 6, 8, 9, 11, 16 and 18) are "pro-technology" statements. One example of a pro-technology statement is item 2: "I look forward to using a computer/smartphone in my day-to-day work." The other nine statements (items 1, 3, 7, 10, 12, 13, 14, 15 and 17) are "anti-technology" statements. To more easily analyze the data, we have negated students' responses to the anti-technology statements and combined them with the pro-technology statements.

Students' responses to the pro-technology statements tend toward agreement, as shown in the two graphs in the first column of the next page. Breaking the responses up further to computer-related (second column) and smartphone-related (third column) questions, the same trends continue.

Shifts in students' responses between the pre-semester and post-semester CARS tests were minimal, perhaps indicating little to no effect on their technological anxiety based on their laboratory experiences. This is to be expected. The vast majority of these PY 206 students were born between 1990 and 1996. Their attitudes toward technological devices are likely well-established and not easily changed. Meeting 11 times over the course of one semester was not likely to shift their technological anxiety one way or the other.

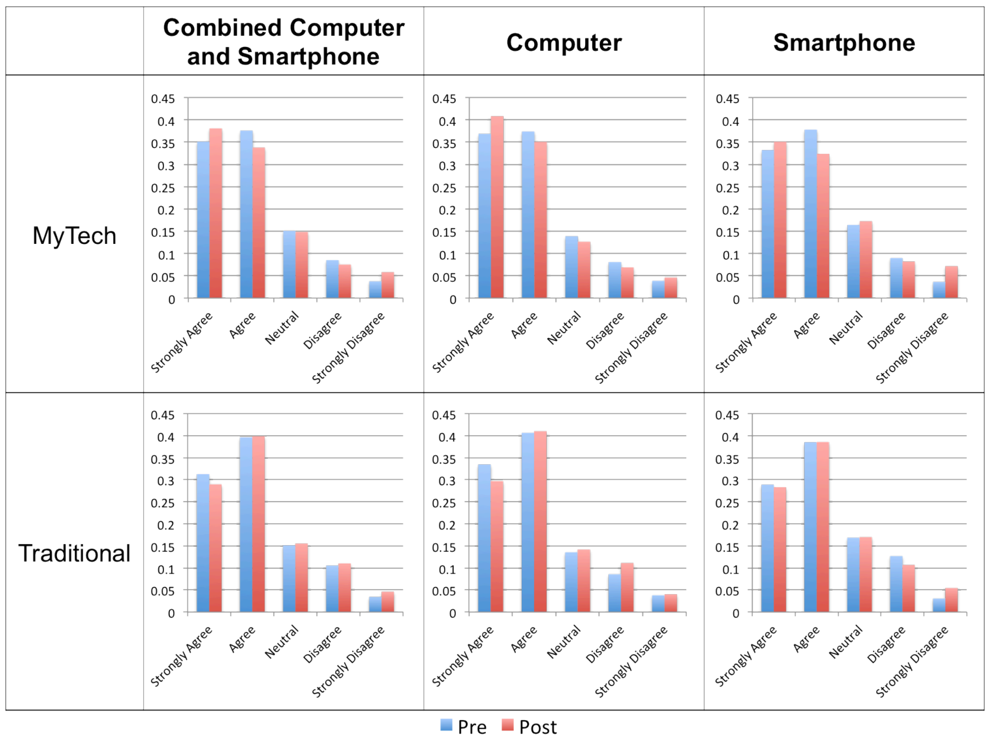


Figure 68 A comparison of MyTech and traditional students' pro-technology sentiments in the Adapted CARS, where fraction of student respondents is on the vertical axis.

The bar graphs on the previous page are somewhat difficult to interpret. To focus in on the magnitude and direction of the shifts, consider the normalized gain. To further distill the data, combine the “strongly agree” and “agree” responses, as well as the “strongly disagree” and “disagree” responses. To help interpret the graphs below, consider a technologically ideal situation, in which students’ attitudes toward technological devices shifted positively. One would then expect them to agree more (and disagree less) with pro-technology statements. Thus, a graph for a student whose attitudes towards technology improved over the course of the semester would have a positive gain in “strongly agree” and “agree” statements, and a negative gain in “disagree” and “strongly disagree” statements.

In our case, again breaking up students’ responses to those that address computer and smartphones separately, we see the strongest movements in traditional students’ computer anxiety and MyTech students’ smartphone anxiety. We observe an anti-technology shift in the computer category for students in the traditional section (red bars in the middle graph). This indicates that students in the traditional section appear to come away from the class with slightly more negative views of computers after their lab experience. On the flip side, we see a strong anti-technology shift in the smartphone category for students in the MyTech section (blue bars in the rightmost graph). This indicates that students walk away from the class with slightly less positive views of their smartphones. Interestingly, the MyTech students have a slight positive shift in their attitudes toward computers (blue bars in the middle graph).

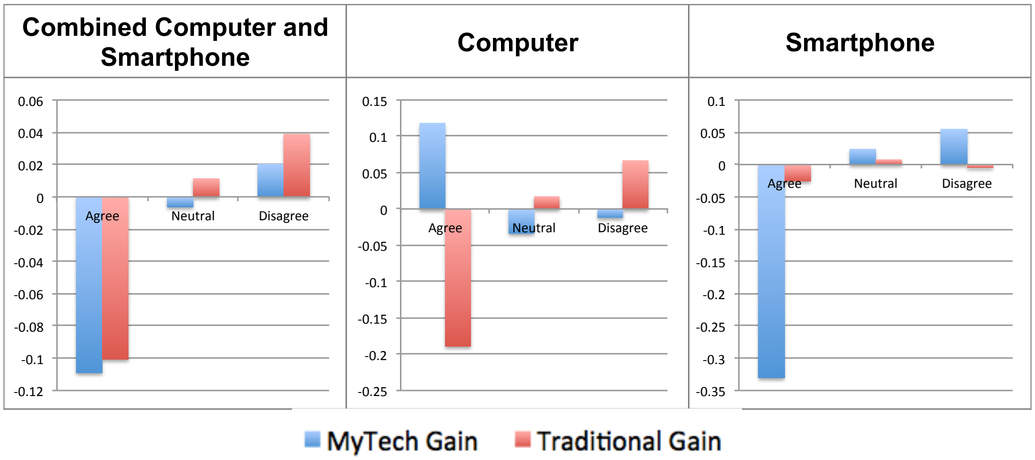


Figure 69 Normalized shifts in anxiety regarding the usage of computers and/or smartphones for students in the MyTech and Traditional sections.

One may simply be seeing here the same impact on college students' technological anxiety that one might tend to associate with any assignment. Perhaps the simple act of requiring students to complete scholastic tasks with technology raises their anxiety level.

In addition to obtaining results from students' self-reported agreement with a variety of statements about technology, I also asked them open-ended questions about how they used their smartphones' sensors outside the classroom. One of the appealing aspects of the MyTech curriculum is that we are able to raise awareness of the capabilities of students' smartphones. This newly-acquired awareness potentially enables them to "experiment" at home. Students were first asked if they had ever downloaded an app that allowed them to access the "raw data (such as battery usage, temperature, acceleration, rotation) produced by the internal sensors in [their] smartphone[s]." Those that affirmatively responded were then asked what they measured with the app. The table below provides counts of students' free responses to this question.

Table 13 Counts of students' responses to the raw data accessed in their smartphones

	MyTech		Traditional	
	Pre	**Post**	**Pre**	**Post**
Battery usage	8	4	4	6
Memory storage	2	3	1	2
RAM Usage	5	1	0	1
CPU Speed (Clock Frequency)	2	0	0	0
Core Temperature	2	1	1	3
Phone Specifications	1	0	0	1
Level/Balance	2	0	1	2
Microphone Input	0	0	1	0
Light Intensity	0	0	0	1
Gyroscope	1	1	1	1
GPS	3	2	0	0
Compass	1	0	0	0
Acceleration	0	6	0	1
External Temperature	3	2	2	0
Sleep cycles	1	0	0	0
Internet Connectivity Speed	1	0	0	0
Mobile data usage	1	0	0	0
MAC address	1	0	0	0

One might notice that the largest jump in pre- and post-test responses occurs with the "acceleration" measurement, which occurs in the MyTech section. In addition to quantitative counts of students' responses, some students provided context for their measurements, including finding their “acceleration while longboarding” and “testing out the app whilst walking and moving my arm in a variety of ways.”

Students in the second and third semesters of the study were also asked for their thoughts on “using [their] smartphone in a physics lab.” All of the students’ responses are provided below. They have been separated by those who had no experience with the app prior to answering the question (responses to the pre-test in the MyTech section and pre- and post-tests in the control sections) and those that had experience with the app prior to answering the question (responses to the post-test in the MyTech section). First, we shall present the responses of inexperienced students with concerns:

- How are we going to use them? Will we need new apps? What if we do not have the newest phones on the market (such as iPhone 4 vs 5)?
- I am skeptical because of the problems my phone gives me at random times.
- I am apprehensive about using them in lab. I don't particularly like using smartphones, even thought they are useful. I'm willing to try something new, but I have my doubts about their effectiveness in a physics lab.
- Screen too small, but handy for simple operations/searches.
- Mixed emotions, a little concerned something will happen and I will lose all my data.
- I’d prefer the dedicated tools for the job.
- I think the computer is better.
- I think it is a horrible idea. It limits your ability to do a lab as opposed to a computer.
- I really don't want to; however, I know it is a necessary device to use [in control group]

We can also consider the responses of inexperienced students who are excited and are optimistically anticipating possible labwork:

- Excited, and feel it is almost equivalent to using a computer in class.
- I am optimistic because I have never used my smartphone in a lab.
- I think it would be interesting because I have not used a smartphone specifically for a lab before.
- It's a good tool and I want to try it out in a lab.
- Sounds nice.

- I think it will be an interesting venture.
- It seems like a swell way to use modern technology to better conduct scientific experiments.
- I am open to it and I think that it will allow labs to become less outdated.
- It seems very intuitive and would be very useful knowing that entering data in a shared computer can sometimes prove difficult.
- It's good to be able to use something that is so common in society today, and that is, pretty much, on my person at all times.
- I feel that it will be a good exposure. One that I will learn a lot more than I already know about technology.
- I think it could be helpful, especially in the right ways.
- I would use a smartphone in physics lab if presented with the option.
- I think using the internal mechanisms of the phone to collect data is new and interesting.
- I think it's practical. In a work place setting, we don't have to memorize equations and do problems by hand. We have tools and should understand concepts.
- If it would actually be helpful I don't see a reason to not use it.
- I would welcome the idea.
- It can be positive if implemented correctly and with the right apps.
- I think it would be beneficial to use smartphones. They are almost as good as computers.
- Would be interested to see how accurate it was.
- It seems like an interesting subject and I would like to see it implemented sometime in the near future.
- I am comfortable using a smartphone for a physics lab because I am unfamiliar with the technology. I feel that though I am uncomfortable, I would be willing to use it if taught.
- It will be easier to access data/tools needed for labs.
- If they have real useful application in data collection then there's no problem using them.
- I think it should be implemented.
- It can be productive and beneficial if used properly.
- It can be useful to have one object that can fulfill multiple tools.

Some of the inexperienced students' responses were completely neutral:

- I'm interested to see how it will work.
- It will be interesting to see how well it works.
- I am curious to see how it will work, and excited to learn ways to use different technologies to solve problems rather than just my calculator.
- I think it could be very useful and cut cost of equipment, but it could distract people from their work.

- I think it could be beneficial but it would be distracting to many students who wouldn't stay on task. It could be very enriching if it was used in a way that maximized learning and got me excited about using it.
- I will use it if we have/need to. I am comfortable operating my phone/apps.
- I feel it can have useful applications for it; however, can become a large distraction.
- I believe that smartphones are useful in a physics lab but come with the drawback of being very distracting at times.
- Honestly, I have mixed feelings because I have only had a smartphones for two weeks and I am just getting used to it.
- Would be difficult concept to grasp, but still manageable and will certainly help.
- They can be useful if used correctly, but could also lead to distractions.
- I think it would be interesting and would grab my attention but would distract many others.
- I don’t think they are needed.
- cool, would need clear manual (or I'll get frustrated); I don't want to pay for it
- I would not mind it. I would prefer to use a computer or tablet because of the small size of smartphones but I could handle it.
- I think it would be fun but not something that would be needed for learning.

In addition, consider MyTech students’ post-semester thoughts on using the smartphone in their physics lab. Some responses were negative:

- I did not enjoy it due to the errors we got in our data multiple times. I felt like it wasted a lot of time and actually once prevented us from completing a V-Python program that was due at the end of the class.
- I think it was more of a hassle than a help. It was more work to try to record his on the smartphone and it often produced results that weren't way clear and were quite difficult to interpret.

Others positive:

- It was useful, allowing an accurate measurement of what motion the object/phone experienced.
- They could be useful.
- I think it can be a very useful tool to gather otherwise difficult information.
- It's a nifty idea and good [indecipherable]. You can do a lot more with a phone to read data than you can with rudimentary tools.
- I enjoyed it and thought it helped speed the process along.
- It is a new method that is relatively more accurate.

- It makes things a lot more common to the user since smartphones are already a part of everyday life.
- I believe it is a good idea. I'm sure it is cheaper than buying lab equipment to measure values.
- I believe it is a good idea. I'm sure it is cheaper than buying lab equipment to measure values.
- I think it's a great experience that helps out with the resources used in lab-- the student can provide the tool that gives the information that we work with.
- It worked very well and went smoothly compared to what I was expecting.
- It is nice having the tools to measure quantities used in physics in your back pocket. It is also more familiar using a phone and you can focus more on the concepts involved instead of how to operate the equipment

And still more were somewhere in between:

- I thought it went well but was a bit unreliable at times.
- It can be useful but, as with everything, it has its drawbacks.
- The phones were interesting to use, but I thought the work we did on the computer was more useful.
- I don't know; don't particularly feel strongly about it.
- It works okay but people having different phones can cause problems.

Students' responses were thusly categorized into positive, negative and neutral bins. Students with background using the smartphone in the physics lab were slightly more likely to have positive thoughts regarding the experience. You will notice that responses from students in the traditional section were also recorded. These students were asked to simply share their thoughts on the prospect of including smartphones in their laboratory coursework.

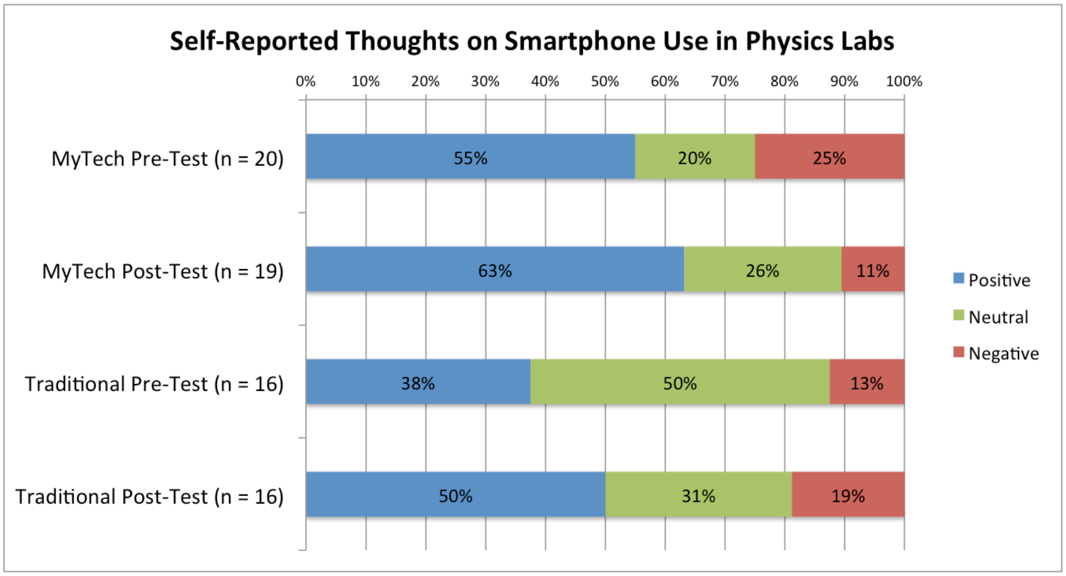


Figure 70 Students' thoughts on smartphones in physics by MyTech and Traditional students before and after the lab course.

Although the sample size is small, these results seem to indicate that students' concerns and apprehensions about using their phone in the physics labs have been reduced over the course of the semester. In fact, the normalized gain in students' negative responses in the MyTech sections is -0.16 (compared to +0.07 in the control sections). The normalized gain in students' positive responses were comparable (+0.22 for MyTech and +0.20 for traditional). This shift toward less negative attitudes regarding smartphone use in physics labs may be due to the exciting novelty of using the phone in their course or the potential for using the phone outside their lab to "collect data."

8.3. CLASS Results

The Colorado Learning Attitudes about Science Survey is a standard measure for determining students' attitudes toward their physics class. Since the creation of the original CLASS and the first semester of our study, the E-CLASS (for experimental classes) was developed. As a result, we had to modify the CLASS slightly so as to be more consistent with students' laboratory beliefs.

The CLASS allows researchers to determine the verisimilitude between experts' responses and students' responses to statements regarding beliefs about science. The more "expert-like" a student's response is, the more "favorable" it is considered, and vice versa. The CLASS researchers provided an Excel spreadsheet (Adams, n.d.) with that allows for the production of a series of standardized graphs displaying favorable and unfavorable movement.

The first series of graphs display percentage of unfavorable responses on the horizontal axis and favorable responses on the vertical axis. Each data point on the graph represents the favorability and unfavorability of a series of items on the survey that correspond to one or more factors, such as "real world connection" or "sense-making." One might expect that a high percentage of unfavorable responses to any one of these categories might correspond to a low percentage of favorable responses. This line of thinking would suggest that the percentage favorable versus the percentage unfavorable response graphs would take the shape of a decreasing line in the first quadrant. As expected, both the MyTech and traditional sections produce these graphs, with very few differences between the two.

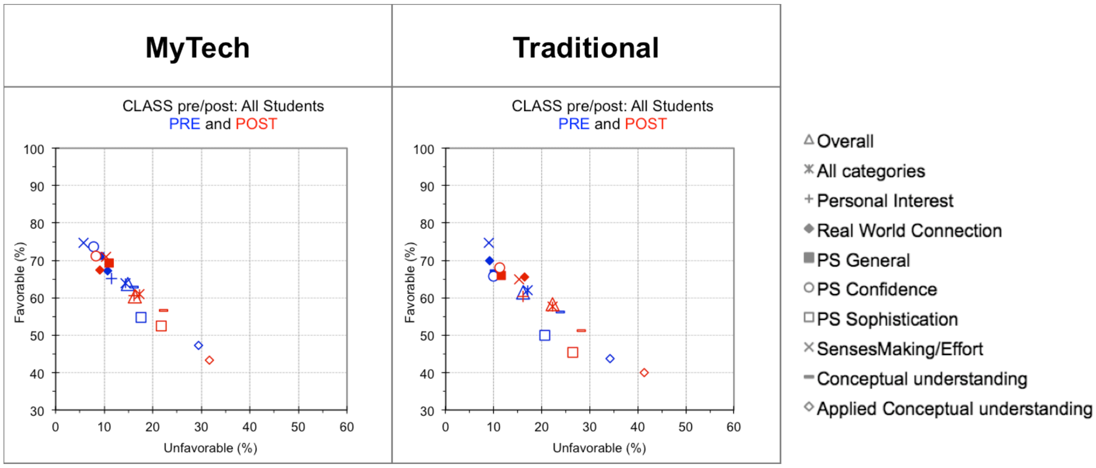


Figure 71 CLASS attitude data for the MyTech and Traditional sections.

Not only do the graphs take the same shape, but we even see evidence of clustering of the same types of categories in the same areas. For example, the "applied conceptual understanding" category (◇) for the pre- and post-test in both the MyTech and control sections are in roughly the same areas on the plots.

In order to examine the shifts more accurately, we can consider the normalized pre- and post-semester movements in both sections. In the graph below, normalized unfavorable motion lies along the horizontal axis and normalized favorable motion lies along the vertical axis. The graph's axes labels, however, are arguably somewhat counter-intuitive. The graph is set up so that in an ideal situation, in which students responded in more expert-like ways, there would be more data points in the first quadrant. (Again, this is likely not what one might think based on the axes titles. One might expect the quadrant with the most data points in an ideal situation would be second quadrant in which we would see a positive shift in favorable responses and a negative shift in unfavorable responses. The “normalized unfavorable motion” axis, however, is defined such that a positive shift indicates fewer unfavorable responses.) Thus, instructors strive for their CLASS shifts to appear in the upper-right (first) quadrant. More often than not, however, researchers see shifts in the lower-left (third) quadrant. Here, both the MyTech and control sections are displayed on one graph.

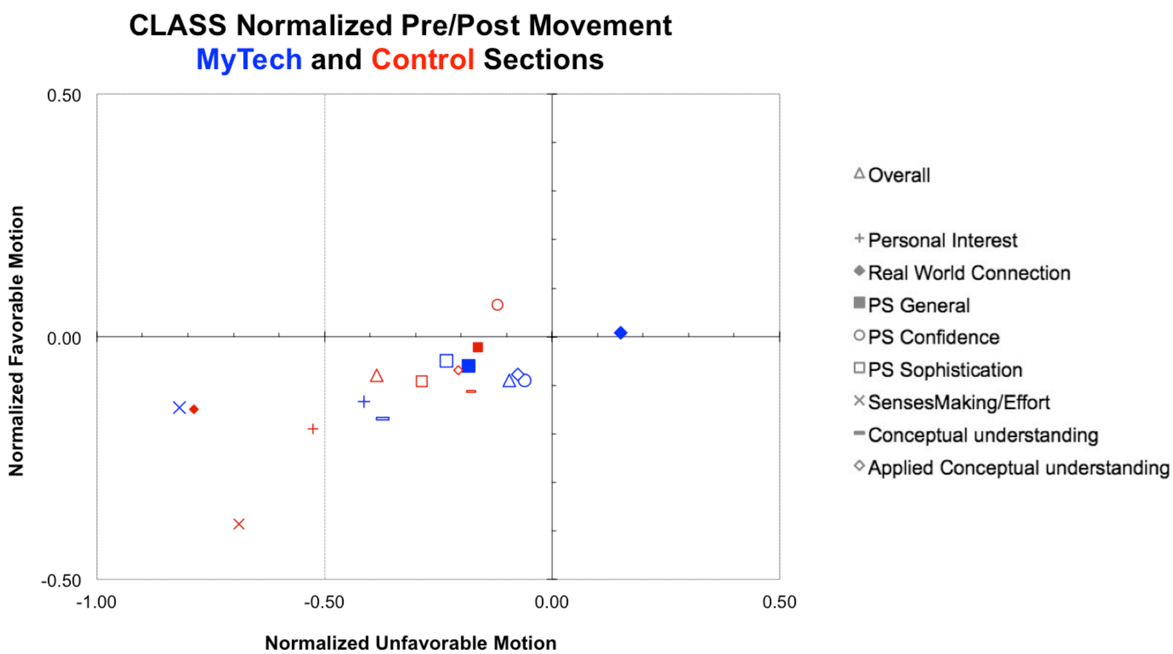


Figure 72 Shifts in the CLASS attitudinal data in the MyTech and Control sections.

Focusing in on the “Overall” shift (Δ), it is clear that the beliefs of the students in the MyTech section barely change at all (i.e., the data point is near the origin), whereas students in the control section become less expert-like throughout the semester (due to increased distance away from the ideal first quadrant).

There are a few other differences between the MyTech and control sections. The most significant difference is perhaps in the “Real World Connection” (♦) category. Perhaps unsurprisingly, students in the MyTech section demonstrate a slight increase along the horizontal axis, indicating fewer unfavorable attitudes (+0.15) whereas students in the control section demonstrate a dramatic decrease along the horizontal axis, indicating increased unfavorable attitudes (-0.79). We will discuss this data point in more detail later.

Fortunately, another startling difference between the two sections emerges in the “Sense Making” (×) category. Here, MyTech students experience less of a negative shift in favorable attitudes (-0.15) as compared to their counterparts in the traditional section (-0.39). Conversely, differences in the “Problem Solving Confidence” (**O**) category manifest themselves. In this case, the students in the control section become slightly more expert-like (+0.07) whereas the students in the MyTech section become slightly less expert-like (-0.09).

Overall, the results from the CLASS for the MyTech curriculum are inconclusive (due to low sample size) but intriguing. The preliminary results are quite unsurprising, given the shift we observed with the adapted CARS toward more positive attitudes regarding smartphone use in physics labs among students with MyTech background experience. While many of the differences between the MyTech and control sections could potentially be excused by the relatively low sample size of the study (n = 32 for the MyTech sections and n = 32 for the control sections), these preliminary data indicate some possible advantages of the MyTech curriculum. We can only speculate as to the reasons that students' attitudes in some categories seem to become more expert-like and more "physics-lab-positive" in the MyTech sections. Students in the experimental section, despite some of their negative experiences, seemed overall impressed with the smartphone's abilities. One might argue that this excitement spilled over into their general physics lab attitudes. One might be able to ascertain these reasons with a future study and a more focused set of survey questions regarding their attitudes directly associated with *the equipment* (as opposed to the lab course overall).

The greatest difference between the shifts in any one category where in the "Real World Connections." The authors of the CLASS used factor analysis to determine the items indicative of students' real-world connections. These items and their shifts in percentages from pre- to post-semester test are presented below.

Table 14 Shifts in items in the "Real-World Connection" category in the CLASS

Item	MyTech			Traditional		
	Agree	**Dis-agree**	**Net Shift**	**Agree**	**Disagree**	**Net Shift**
"Learning physics changes my ideas about how the world works."	**4%**	-5%	EXPERT	**-1%**	4%	
"Reasoning skills used to understand physics can be helpful to me in my everyday life."	**-1%**	3%		**-4%**	3%	
"The subject of physics has little relation to what I experience in the real world."	1%	**-5%**		7%	**-1%**	
"To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed."	**3%**	-5%		**-12%**	15%	NOVICE

In the table above, the bold typeface indicates the percentage of students that agree with experts' beliefs. Thus, in bolded boxes, we want to see a high, positive percentage for agree and a high, positive percentage for disagree. As stated in the CLASS worksheet, "If the net shift in student beliefs for a question is significant, the direction of the shift is indicated with a 'NOVICE' or 'EXPERT,'" where "novice" indicates low percentage shifts and "expert" indicates high percentage shifts.

Students' responses to the statements above became slightly more expert-like in the MyTech section than in the traditional section (where responses became significantly less expert-like). This suggests an interesting conclusion regarding the way in which students relate their physics lab experiences to the real world. Perhaps, by MyTech students using their own personal devices, they are able to "insert themselves" into the physics experiment.

For example, the simple harmonic motion lab in the traditional curriculum simply requires the student to time the period of a swinging pendulum, like an outside observer. In the MyTech curriculum, however, they are asked to position their phone at the bottom of a physical pendulum and are asked to consider the force experienced by the smartphone as it oscillates back and forth. In this way, MyTech students are perhaps more likely to consider what it's like to be *in* the physics lab experiment, thereby strengthening the "real world connection."

The next greatest difference between the shifts in MyTech and traditional lab students was in the "Sense Making" category. The items correlated to sense making include:

Table 15 Shifts in items in the "Sense-Making" category in the CLASS

Item	MyTech			Traditional		
	Agree	Disagree	Net Shift	Agree	Disagree	Net Shift
"I am not satisfied until I know why something works the way it does."	**-22%**	6%	NOVI CE	**-14%**	7%	NOVI CE
"In doing a physics problem, if a calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem."	3%	**-13%**	NOVI CE	0%	**3%**	
"In physics, it is important for me to make sense out of the formulas before I can use them correctly."	**-7%**	6%	NOVI CE	**-7%**	17%	NOVI CE
"Spending a lot of time understanding where formulas come from is a waste of time."	3%	**-4%**		4%	**-25%**	NOVI CE
"There are times I solve a physics problem more than one way to help my understanding."	**0%**	13%	NOVI CE	**-16%**	12%	NOVI CE
"When I solve a physics problem, I explicitly think about which physics ideas apply to the problem."	**25%**	0%	EXPE RT	**-1%**	4%	
"When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented."	**-4%**	0%		**-8%**	0%	

Students in the MyTech section did not appear to care any more about the way things work than their traditional counterparts. However, the most significant difference occurs with the penultimate item in which students indicate that they give considerably more thought to which physics ideas to apply to a given problem. This might have something to do with the forethought necessary for setting up a MyTech experiment and determining, say, the axis of interest.

8.4. Lab Equipment Survey

Extra time and energy were put into the description of how the sensors collect data in the MyTech curriculum in the hopes that these students would acquire a deeper understanding of their experimental design. In so doing, the first lab was developed around this idea, and several questions sprinkled throughout the course were also added on. Therefore, I administered the Lab Equipment Survey to students in both the MyTech and traditional courses during the last semester of the study. The survey was given out prior to lab 5 so that students in both sections had some experience with the sensors they were using in their labs. Students in the MyTech section were asked about the accelerometer (which they had used in three different labs) and students in the control section were asked about the spring force sensor (which they had used in one lab). One might suspect that students in the MyTech section were at a considerable advantage due to the sheer number of times that they had recorded data using the sensor of interest. Students were asked to rate their confidence level of understanding the sensors on (on a five-point scale) and then explain to their hypothetical 12-year-old brother how the sensor measured the quantity of interest.

Unlike the students in the traditional sections, students in the MyTech section had been exposed to some theory regarding the most fundamental aspects of the sensors' measurement techniques. For example, lab 1 provided MyTech students with a simplified ball and spring model for the accelerometer.

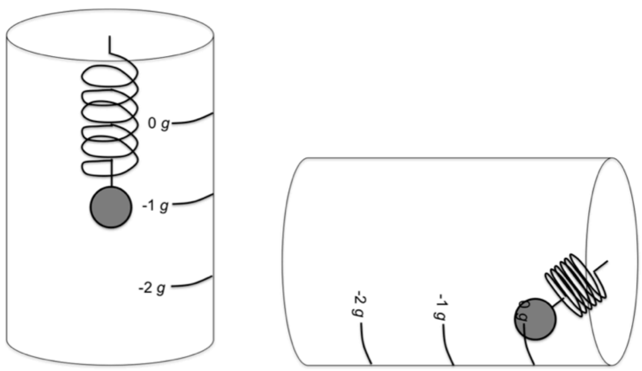


Figure 73 Schematic of the ball-and-spring model for an accelerometer.

The MyTech students attempted to explain the accelerometer's measurement technique (where the number preceding their response was their corresponding self-reported confidence level):

- Confidence level 3: "The phone has a gyroscope which allows data to be taken in 3D. Using bluetooth and wireless signals the phone is also able to measure speed (velocity) and acceleration based on location."
- 2: "The gyroscope in the phone can measure things, such as acceleration, in three directions. When the phone experiences accelerations in either three dimensions (x, y, z), the gyroscope can calculate the acceleration by the amount of change in work it experiences to 'stabilize' itself."
- 3: "Magic".
- 2: "Because an app on the phone allows it to use an accelerometer."

- 4: "'There is an accelerometer in this phone that can measure how quickly it waves around.' I'd start up the phone's accelerometer and explain the graph."
- 3: "I would be able to explain the general physics principles behind certain concepts however not specifically how the phone was able to measure the data."
- 4: "It has a device in it that measures the force of gravity in certain directions."
- 3: "I have no idea. I just know how to read it."
- 3: "The sensor in the phone that has the GPS, the sensors for making the screen sleep when talking."

Students were encouraged to provide sketches, but only two of the 10 responses included diagrams, and those that did attempted to falsely connect the inner-workings of the accelerometer with those of the gyroscope.

Figure 74 MyTech students attempted to explain how the accelerometer records data by providing sketches of gyroscopes.

Despite best efforts, students in the MyTech section did not have a clear sense of how data were collected by the accelerometer so even though they were nearly halfway through the semester, they still struggled to determine the axis of interest on their smartphones. This suggests that the expectations of students in the introductory mechanics course were a bit too high. This is consistent with the AAPT Recommendations for the Undergraduate Physics Laboratory Reform[88] published last year. The AAPT's recommendations regarding measuring devices is that, at the introductory level, "Students should be able to *use* measuring devices and apparatuses to make measurements consistent with the content covered in the course," whereas at the advanced level, they recommend "Students should be able to *understand* the measuring devices and apparatuses and make measurements appropriate to the content of the course." We therefore recommend that future implementations of MyTech labs only require students to understand the basic aspects of the sensor detection methods.

Unsurprisingly, students in the traditional section were similarly puzzled by the way in which the spring force sensor took data. These students had likely never given the question any prior thought, but some made reasonable speculations:

- 3: "Although I do not know the working mechanics of the microchips of the sensor, the spring has a certain 'bounciness' to it and through knowing the exact number that represents this 'bounciness,' they can calculate the form through using an equation."
- 4: "I would tell him that the displacement of the spring is multiplied by the k constant (already known) to calculate force."

- 1: "I would say it measured force the motion of the projectile and the compacting of the spring."
- 3: "The spring sensor measures the Δx of the spring and multiples by the spring constant in order to record the force of the object."
- 2: "Since Hooke's Law says $F = kx$. I would say the force is measured based off the amount of spring compression."
- 2: "I really don't know myself. I understand how the motion sensor works, though."

- 3: "Relate Energy to Work, and also measure distance to find force."

$$W = F \cdot d$$

Calculatable.

- 3: "Magic."
- 3: "The spring sensor measures how far it is compressed and how long it takes for it to be compressed this distance. We input the mass and it calculates force."

$$F = ma$$

$$x = x_0 + v_0 t + \tfrac{1}{2} a t^2$$

$$F = m\left(\frac{2(x - x_0 - v_0 t)}{t^2}\right)$$

None of the students in neither the MyTech nor the control section provided the correct responses, it could be argued that students in the control section made stronger attempts at answering the question because they tied in known physics concepts. Students in the traditional section referred to Hooke's Law, the definition of work and various kinematics equations whereas students in the MyTech section tended to falsely connect the accelerometer's measurement technique to other unrelated technological capabilities, like gyroscope measurement, Bluetooth technology, wireless signals and the GPS.

These responses suggest that students in the traditional section have a slightly better understanding of the sensors that they use and can more accurately connect them to physics concepts.

8.5. Smartphone App Survey

In the third semester of the MyTech study, we received an Idea Grant from the DELTA (Distance Education Learning Technology Applications) Initiative at NCSU. Part of the DELTA grant facilitated mobile app development and creation. By this point in the study, it was too late to implement develop, create, share and implement a new app into the current semester's curriculum, but we launched a movement towards the development and creation of a freely available MyTech app.

We attempted to use students' feedback to strongly guide the design of the new app, which is to launch simultaneously on the iOS and Android platforms in March 2015. A series of issues that students encountered emerged from observations of the video data. In the Fall 2014 semester, we administered a Smartphone App Survey that attempted to collect more information about issues that students had happened upon in the course of their lab. The pre-known issues were provided as a list of multiple-select options for students to circle (to determine frequency and priority of issues) and an additional free-response space was also provided. The eleven responses to the Smartphone App Survey proved invaluable.

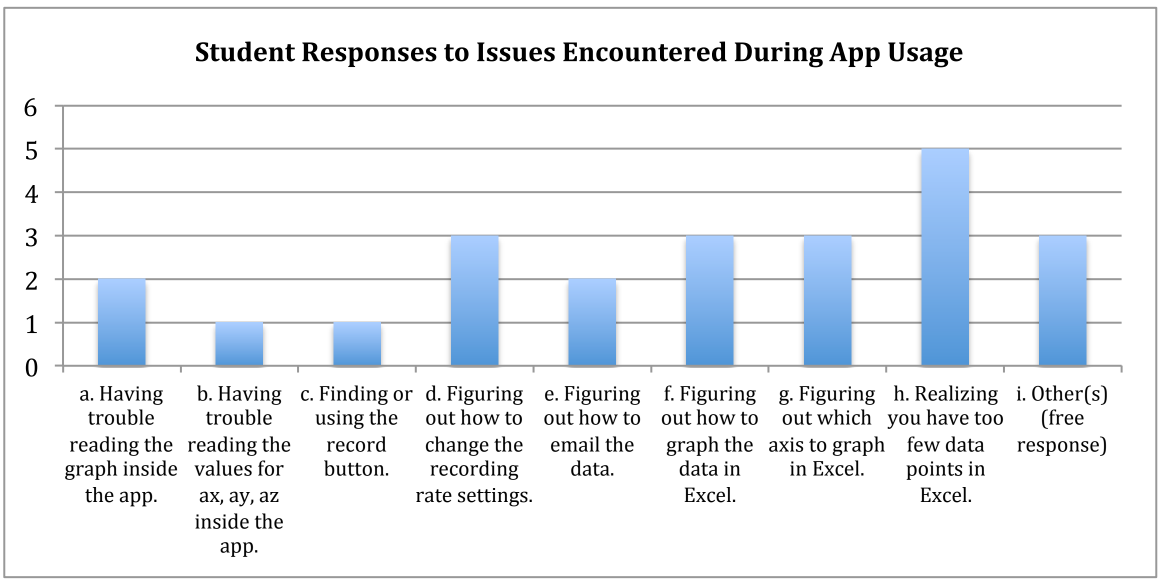


Figure 75 MyTech students were asked to provide a list of issues that they had encountered with the pre-existing apps. Their responses have helped guide the design of a new MyTech app.

The most common issue students encountered was realizing that they had too few data points in Excel. This is most likely to occur if a student has not changed the default recording rate in AndroSensor or SensorLog. Changing the default recording rate to a more reasonable value is a quick and easy fix when designing your own mobile app. The other three most common responses (“figuring out how to change the recording rate settings,” “figuring out how to graph the data in Excel,” and “figuring out which axis to graph in Excel”) can also be easily fixed with the institution of a brief app tutorial upon first opening it or an easily-accessible help feature within the app.

Oddly enough, students didn’t unanimously agree that such a help feature would be useful to them. When asked about whether or not a help or tutorial feature could have helped with some of these issues, half of the students responded affirmatively, and the other half responded negatively.

Students suggested that the apps were apt to glitches in the “other” responses. In one case, AndroSensor had an issue where “only once did the time measurement skip and mismeasure intervals.” Two students using SensorLog suggested that the recording rate needs to be in Hertz and at a higher maximum. Due to TA 3’s misconception regarding recording rates in Hertz, one group struggled to determine an ideal recording rate setting. While the MyTech app will contain an appropriate default recording setting, TA instruction should include an in-depth discussion of the meaning of recording rate and the units provided by the app.

The Smartphone App Survey also allowed students to comment on any changes or additions they would make to the app if given the chance to redesign it:

- Less buttons on homepage. Bigger graphs.

- The application is pretty solid; the scale is a bit small; only if you strapped it to a rocket could you see a spike on the graph
- Less scientific looking on the app and more user friendly.
- Data files with only the data needed.
- None that I can think of.
- Make the Android version work like the iPhone version. My team ended up using iPhones for everything because the Android version was glitchy.
- None. The time issue was fixed as well.
- Make separate tabs for each measurement graph (I don't need to see gravity if I'm trying to read the gyroscope); in reference to (3e): non-existant in app, I assume.
- In my opinion if the issues in #3 were fixed, the app would be good.
- Allow for more specific settings

The students in the MyTech section were very forthcoming with changes and additions to be made for a future app. Prior to administration of the survey, for example, several students independently asked the TA why the computer science department hadn't been employed to create a better app. This indicates a level of disapproval of the existing apps.

9. MyTech App Design

Fortunately, through the NCSU DELTA Idea Grant, we were able to begin work on designing the new MyTech app. We use students' comments about the existing apps as a guide. As a starting point, I reviewed my interviews with the students at Meredith College in Raleigh, NC. First, students at Meredith supported the need for a tutorial feature:

- "results were harder to understand on the phone"
- "data retrieval was a little too complicated, but not too bad since [the TA] was available to explain the graph-making process"

- “We almost always had to ask questions about how to use the app or what a particular value meant”
- “time spent learning how to use the phone … was tedious and took significant time to complete”
- “I understood what the acceleration was, but I didn’t understand the other things like the gyroscope and stuff”
- “some more information would be helpful…like how to use the software beforehand”

Using these comments, it seemed reasonable that the best place for additional information would be within the app itself. The Meredith students demonstrated curiosity about the accelerometer recording mechanism. These sentiments echoed those in the Lab Equipment Survey administered in Fall 2014 to NCSU students.

- “I need visuals that the smartphone didn’t give me”
- “It was cool to use an everyday piece of technology and to see how it could work with different physics concepts. But, it got a little tedious because we didn’t understand why (the mechanism) it was doing some things.”
- “We didn’t have enough physics knowledge (too low of a level) to understand all the data given by the smartphones”

These comments suggest the desire for a “window” to the inner-workings of the accelerometer. I initially intended to develop a simulation that would allow students to “pull off the screen” and see “inside” the smartphone. This simulation concept later developed into a working ball-and-spring model accessible within the MyTech app.

In addition to large-scale changes, some students at Meredith listed specific aspects of the app to improve:

- “the numbers were too small to read”
- “precision was a problem… when you were holding it, you had to be really precise because it always looked like it was moving”
- “I wasn’t sure if there was a record option” [after a lab where they were not required to use the record option]
- “I wish you could go back and see your recorded data in graph form”
- “the colors [on the graph] were terrible”
- “I would prefer the traditional equipment because you can stop the graph from going but on the smartphone it keeps going”

These detailed observations led to small-scale ideas for the new MyTech app. Finally, many of the Meredith students pointed out features of the apps that were advantageous and should remain relatively unchanged:

- “[the app was] useful– allows for easier calculations”
- “The smartphone [was] easier to use– more access to more data”
- “More accurate [than traditional lab equipment]”
- “The labs seemed easy when the data-retrieval was explained and dropping a smartphone or swinging it from a pendulum was fun and seemed to give accurate data”
- “Easier to save and record data [with a smartphone]”

- “You’re not only experiencing the motion but you’re also thinking about it in terms of [motion on] a plane”

Based on these suggestions from the Meredith students and those gained from the Smartphone App Survey, I developed a series of images to serve as a mock-up of the new MyTech app.

9.1. MyTech App Mock-Ups

I created a set of initial mock-up screen shots of the app as it performed some of its most common tasks, including recording accelerometer data, recording gyroscope data, browsing previously recorded data, emailing data, providing full functionality to the ball-and-spring simulation, and displaying tutorial and help files. Consider each mode in the following subsections.

9.1.1. The Accelerometer and Gyroscope Modes

The interface for the accelerometer mode must be clean and intuitive, as students in the MyTech curriculum spend the majority of their time in this mode. Thus, I suggested that the accelerometer mode open by default and contain buttons allowing the user to record data, browse previously recorded data or access any of the other sensor modes. An accelerometer screenshot from the pre-existing AndroSensor (for Android OS) and SensorLog (for iOS) app appear first and second, my mock-up is third, and the mock-up from DELTA’s design team (led by Kelly Fish) is on the right. Students unanimously preferred SensorLog over AndroSensor.

Screenshots from the AndroSensor app are not shown because students unanimously preferred SensorLog to AndroSensor and thus we used the SensorLog interface as a springboard for the MyTech app design.

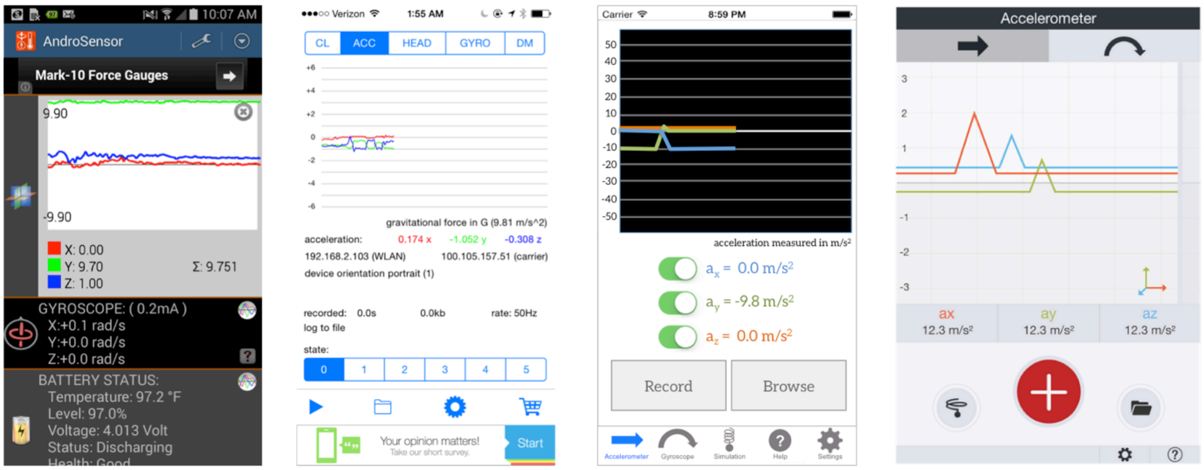


Figure 76 Screenshots and mock-ups from various apps that allow the user to access the phone's raw accelerometer data. The first is from AndroSensor, second is from SensorLog the third and fourth are mock-ups of the MyTech app by Colleen Lanz and the DELTA design group, respectively.

Unlike previous iterations of similar apps, this app would allow you to focus your attention on only certain smartphone axes. In my mock-up, this feature was implemented through a series of toggle switches, but in DELTA's version, one would simply need to tap the appropriate a_x, a_y or a_z box to emphasize it on the graphical output.

The new MyTech mock-ups also suggested that acceleration be measured in meters per second squared, and that the graphical output be clarified by thickening the lines and scaling the vertical axis so that you can more easily make out the plot of the accelerometer data.

While some effort was made to minimize the cognitive load in the accelerometer mode by cleaning up the interface, DELTA's mock-up took this one step further by replacing nearly all of the text with meaningful icons.

The gyroscope mode, in all mock-ups, bears enough resemblance to the accelerometer mode that it does not warrant a second set of mock-ups in its own right. The only aesthetic difference is that the gyroscope would allow for determination of ω_x, ω_y and ω_z and the units would be in radians per second.

9.1.2. Browsing and Emailing Modes

Currently, SensorLog does not allow for the user to review a "snapshot" of the graph of their recorded data. Users must wait until they have emailed the data to themselves and graphed them in Excel to even determine what the data file contained. The browse mode simply allows users to attach the file of their choosing to an email for future analysis without any kind of preview of the data contained within.

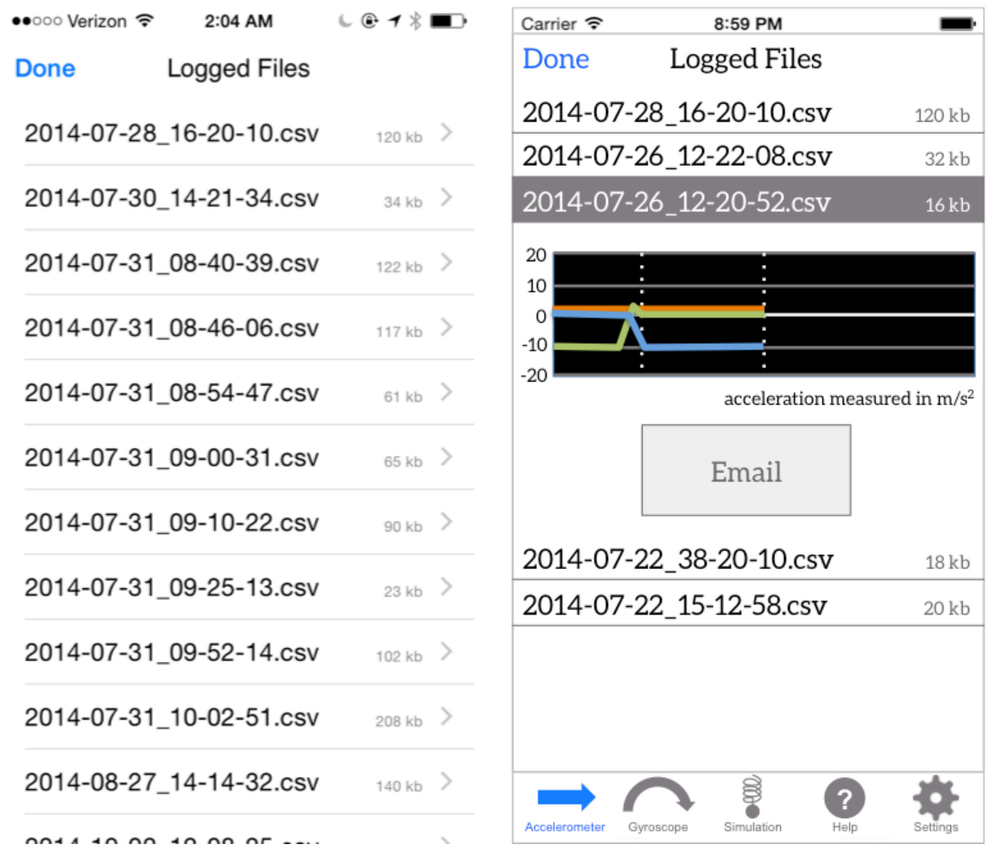


Figure 77 The browse feature of SensorLog (left) and a mock-up of the new browse and review feature in the MyTech app (right).

The mock-up of the new browse feature allowed for slightly more sophistication. In it, tapping on a file name allows for a drop-down panel displaying a snapshot of the recorded data so that students can more easily determine the file of interest *before* sending it to themselves and graphing it in Excel.

The SensorLog app currently sends a meaningless default email message along with each of its attachments. While the opportunity to change the message exists prior to students sending the email, few students take advantage of it and end up with a series of subsequent files residing in their inbox without any descriptions. This particular situation is quite common when students are working through MyTech labs that involve multiple trials.

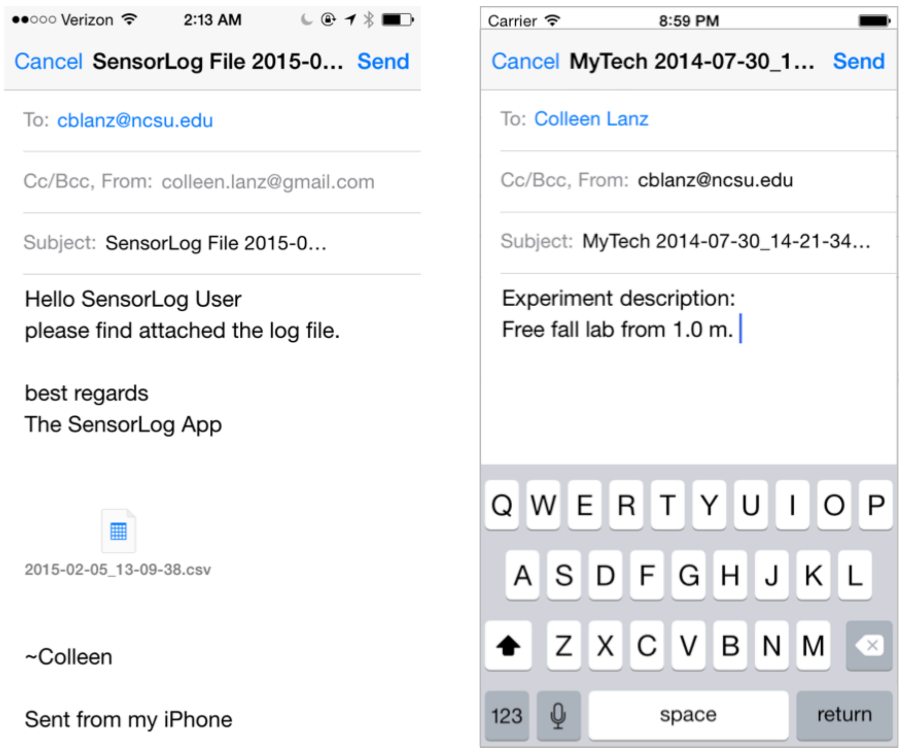


Figure 78 A screenshot of the emailing feature in SensorLog and a mock-up of a similar feature in the MyTech app

I believe that by simply prompting the user for a description of the lab in the email message window will encourage many students to include it.

9.1.3. Simulation Mode

Because SensorLog was not designed specifically for students, no effort was made to illustrate the ball-and-spring model with which the accelerometer operates. Up until this point, it could be argued that the only changes to the MyTech app are cosmetic. Here, we establish new ground for sensor apps.

A ball-and-spring system (such as the ones illustrated in the mock-ups below) simulates the accelerometer sensor's motion within the phone. Here, the simulation will only display in one dimension so as to reduce initial cognitive load. When the phone is held upright, the spring would stretch so that the center of the mass reaches a reading of -9.8 m/s^2, as shown in the first screenshot below. As the phone is thrust upward, the spring would stretch t=so that the center of the mass matches the accelerometer reading, as shown in the second screenshot. The third screenshot illustrates the position of the ball-and-spring model when the phone is in free fall, so that the accelerometer reads 0 m/s^2. Additionally, Dr. Robert Beichner suggested that students might want an option to "turn on" a pen that is attached to the mass to mimic how the accelerometer graphs are created, as illustrated in the fourth screenshot below. The DELTA design team's mock-ups are below.

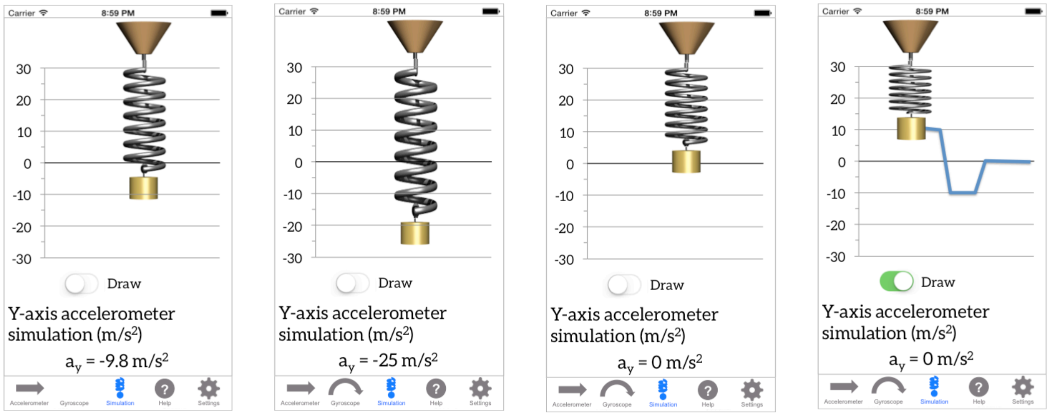


Figure 79 Mock-ups of the ball-and-spring simulation in the MyTech app by Colleen Lanz. The first image would result from the phone being held upright and stationary, the second from being thrust upward, the third from being thrust downward. The fourth illustrates the "draw" feature.

Figure 80 Mock-ups of the ball-and-spring simulation in the MyTech app by the DELTA design team, led by Kelly Fish.

9.1.4. Tutorial and Help Sections

One of the aspects frequently lacking in the apps currently on the App Store and Google Play store is a help or tutorial feature. Apparently most app authors expect that, since users are interested enough in the raw data produced by the internal sensors, they must understand the meaning of the resulting data. This is not the case for most of our PY 206 students. Results from the Lab Equipment Survey, in particular, demonstrate that students are chronically baffled by which axis is of interest. In addition, students often ask their TA before carefully reading through the instructions provided in the lab manual. Perhaps, given the option, students might choose the convenience, conciseness and accuracy of help articles within their smartphone app over their asking for help from their TA.

This suggests that students ought to be introduced to the basic features of the app when the open the app for the first time. Such tutorials are quite common among the more advanced apps. My app mock-up suggested a dark overlay with white text, allowing users to tap through guided arrows, pointing out some of the important buttons.

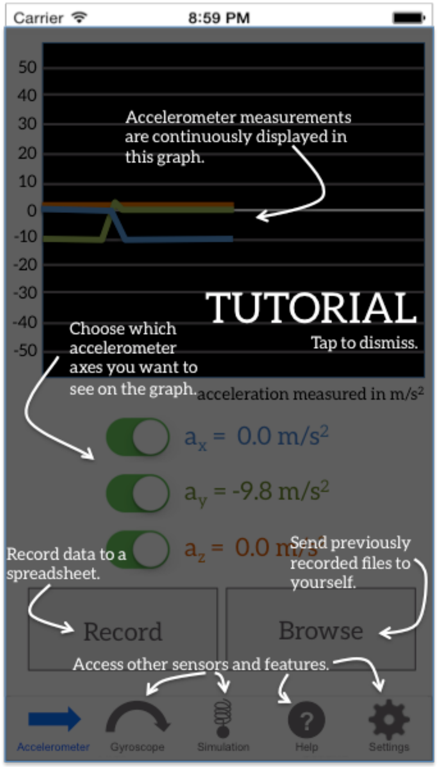


Figure 81 Tutorial screen mock-up for the MyTech app by Colleen Lanz.

Similarly, the DELTA team suggested a swipe-able overlay that emphasizes certain features on each page of the tutorial. Students would have the opportunity to close out of the tutorial at any time by tapping the “×” in the upper right. They could also choose to review the tutorial at any time by choosing “tutorial” in the help menu.

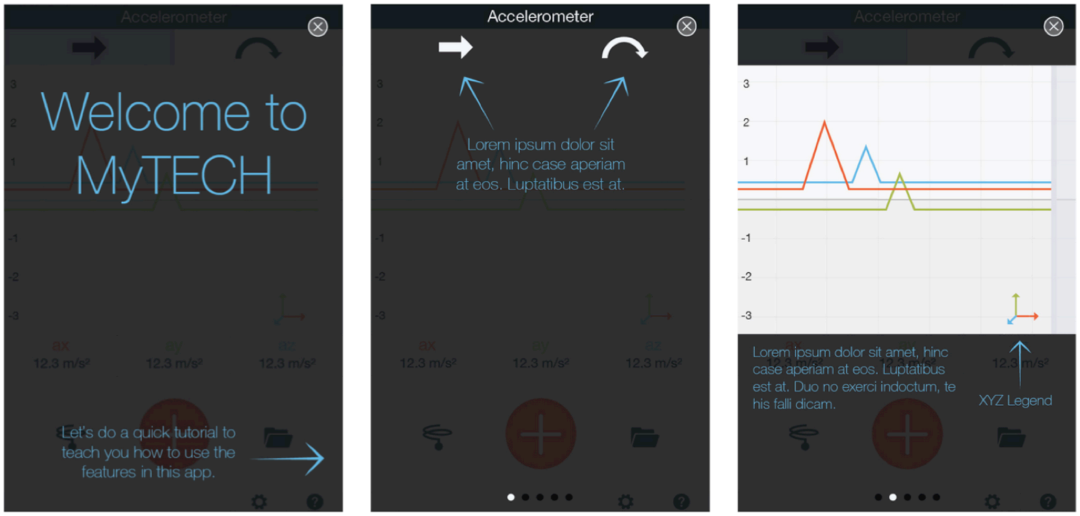


Figure 82 Tutorial screen mock-ups for the MyTech app by the DELTA design team, led by Kelly Fish.

In addition to providing some insight into the technical aspects of the app, the help feature ought to also allow students to access answers to common conceptual and procedural questions. I used observations of students' most commonly encountered issues as well as responses to the Smartphone App Survey to shape the articles offered by the app. Ideally, students would tap on a question and a brief HTML-based article would respond to that question. The articles are designed to be rich in illustrations so that students can answer their questions as efficiently as possible.

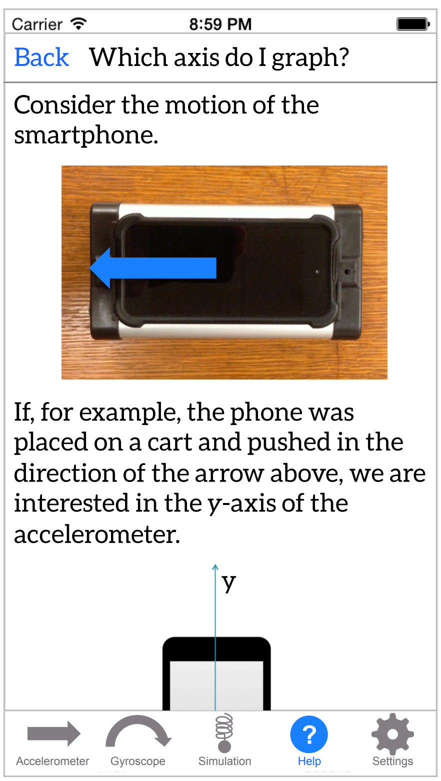


Figure 83 Mock-up of a help feature in the MyTech app by Colleen Lanz.

The inclusion of these concise help articles is intended to: i) improve students' user experience and allow them to review important experimental methods prior to requesting help from a TA; ii) help students gain more independence in the laboratory; and iii) allow them to become more comfortable with collecting data on their smartphones.

Previously existing apps like SensorLog and AndroSensor housed the basic features necessary to implement data collection with smartphones in the MyTech curriculum. However, the app design proved burdensome and, for many students, counter-intuitive. One of the primary goals of the MyTech project was to allow for devices that were more familiar and thus easier to use for students. The MyTech app's user interface, therefore, is *key* to the success of the MyTech curriculum. We made efforts towards cleaning up the interface so that it would be clear how to complete common tasks like recording new data and analyzing them. Furthermore, the addition of a rigorous help feature allows students greater autonomy when collecting data and may lead to increased confidence with technological devices.

10. Future Work

Preliminary results from the TUG-K, CLASS, and quantitative temporal video analysis indicate that the additional time spent in the MyTech instructional lab is not leading to gains in kinematics graph skills or physics lab attitudes. The data from the three-semester MyTech study allow one to identify some likely aspects of the curriculum that could be improved.

10.1. Improving the Existing MyTech Curriculum

First, students in the MyTech sections, despite best efforts, are still not gaining a deep understanding of how the accelerometer records data. This causes issues in trouble-shooting and experimental design. Results from the Lab Equipment Survey suggest that neither students in the MyTech nor the traditional lab sequence gain a deep understanding of the sensors that they use to record data in their labs. The primary difference in these two courses, however, is that students in the MyTech section are purposefully given more ambiguous lab manuals that make them responsible for determining the axis of interest.

We can attempt to "solve" this problem in two ways. One way involves making the MyTech labs more "cookbook"-like. This method bypasses students' issues with correctly determining the axis of interest, but takes a step away from methods that promote autonomy.

The second way of solving this issue requires improved guides for accelerometer understanding. We have already taken one step toward enhanced understanding of the accelerometer's ball-and-spring model by including a simulation of it within the MyTech app. We hope that this new feature will allow students to visualize what is going on inside their smartphone. We hypothesize that students will be able to extend the comfort level they will obtain with accelerometers in one dimension to three and more easily determine which axis' accelerometer they will want to graph in Excel.

We can further the accelerometer's connection to the real world by using a physical classroom demonstration of a three-dimensional accelerometer.

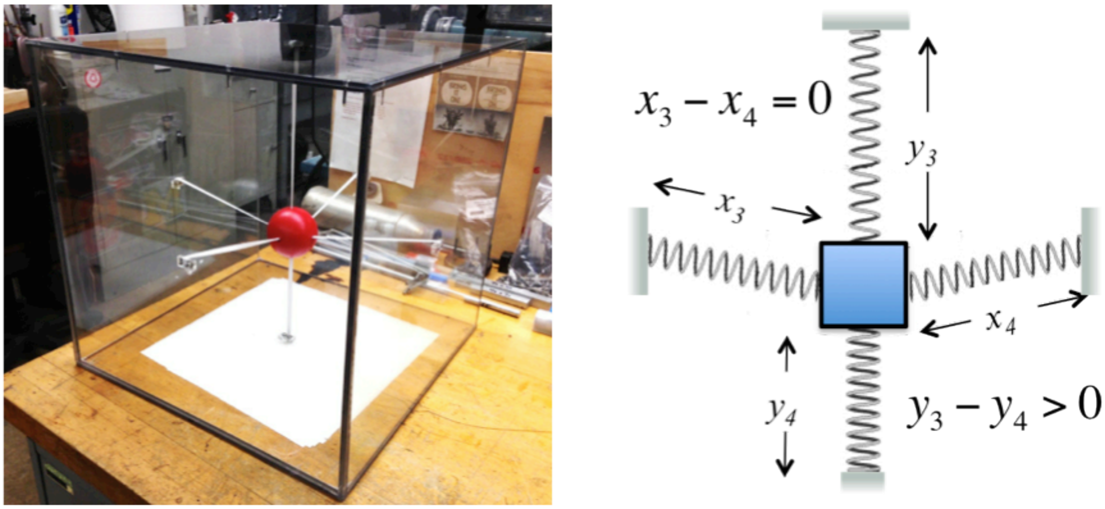


Figure 84 The ball-and-spring accelerometer classroom demonstration created by the NCSU College of Science Machine Shop (left) and a schematic illustrating the way the accelerometer detects acceleration (right).

With the help of the machine shop, we developed a classroom tool to further illustrate the motion of a three-dimensional accelerometer. The model houses a red spherical mass connected to a series of six elastic bands (two along each "accelerometer axis") within a cube of Lucite. The bottom panel has four casters on which the model can freely move. Just like the internal smartphone accelerometer, the model's spherical mass is pulled down by gravity causing the top band to stretch. This corresponds to a reading of $-1g = -9.81\ \mathrm{m/s^2}$ along the axis perpendicular to the Earth's surface. As the model rolls freely in a plane parallel to the Earth's surface, the other four elastic bands extend and compress appropriately.

The goal of both the in-app ball and spring simulation as well as the real-world ball and spring model is to directly connect the motion of an object with the accelerometer readings. We anticipate that both tools would facilitate students' comprehension of the accelerometer's recording process, leading to a deeper understanding of lab concepts and an improvement in lab affect.

In addition to improving the guides for students' understanding of the accelerometer, we must also turn our attention to other ways to enhance the students' and TAs' trouble-shooting process. In this category, I believe there are two primary aspects of the MyTech curriculum that need attention.

First, I believe that we should strive to boost students' laboratory autonomy. This is especially true if we are to implement MyTech into a distance lab course. It is clear from observations of students working through the MyTech labs that they do not always look for answers to their questions in the lab manual. Often, students will call over a TA for help or even Google the answers to their questions before fully investigating the information already given to them. I suspect that students are intimidated by the lengthy document, and thus seek answers elsewhere. We can stave off some of these issues by providing brief answers to common questions directly within the MyTech app. The addition of the tutorial for technical problems and a series of help articles (akin to a "Frequently Asked Questions" section) for procedural and conceptual problems will hopefully alleviate TA-dependence and improve students' comfort level with the experimental tools in their lab.

Secondly, we must spend more attention on TA instruction, specialized for the MyTech curriculum. For this three-semester study, the three TAs underwent the traditional TA instruction, which included some combination of a discussion of pedagogical methods and an attempt by the TA to perform the traditional lab experiment for him/herself. In addition to this traditional instruction, the TA met with me at the beginning of the semester and I introduced him to the smartphone and Tracker methods of recording and analyzing data. Even more, I sent out an email with details as to the differences in the MyTech lab and the TA always met with me prior to the lab for at least a few minutes to discuss the unique aspects of the MyTech lab. This often included a demonstration of MyTech data collection. Nevertheless, TAs found their instructional duties for the MyTech section more challenging than the control sections. This is likely due, in large part, to the limited amount of experience they have with the MyTech labs, relative to the traditional labs.

In an attempt to minimize the comfort gap experienced by TAs with the MyTech and traditional curricula, I have written a "MyTech TA Lab Manual," intended to accompany traditional TA instruction. The MyTech TA Lab Manual (see Appendix A) serves to familiarize the MyTech TA with common issues encountered by students in the lab. The Lab Manual was contemporaneously with the development of the new MyTech app, and thus does not include MyTech app-specific instruction. In theory, however, instruction for the new app will be less complicated than that for the pre-existing SensorLog and AndroSensor apps.

The MyTech TA Lab Manual includes an in-depth discussion of the ways in which the accelerometer and gyroscope collect data. The explanations go into greater detail than what would be required knowledge of a PY 206 student in order to satisfy the TA's intellectual curiosity perhaps that of an especially advanced student. The MyTech TA Lab Manual goes on to illustrate features of both of the pre-existing apps so that the TA's level of comfort with an app will not be seriously impacted by the operating system he/she personally uses. In addition, I provide a guide to the basic aspects of Tracker analysis. Still more, the MyTech TA Lab Manual also incorporates keys for each of the 11 labs in the curriculum. Finally, the document provides answers to students' common errors.

Moreover, we can make an attempt to reduce the frequency of students encountering these errors by eliminating or seriously changing lab activities that increase frustration and needless complication. For example, in section 8.1, I argued that students do not really need to determine velocity-versus-time and position-versus-time plots from an acceleration-versus-time plot. Accelerometer data are only "converted" into force data. The integration of the curve to find velocity is unnecessary, as we use Tracker to establish velocity and position data. Lab 1 (Discovering the Smartphone Axes), however, contains an artifact of this earlier train of thought that implied the necessity of such an activity. In lab 1, students are shown a video of a cart, bouncing on an inclined track against a spring bumper. They are given the acceleration curve for one of these bounces and asked to sketch the corresponding velocity and position curve. This activity no longer serves the purpose it was intended for—increasing students' comfort level with accelerometer graphs. As such, it could easily be removed.

Similarly, in lab 5 (Uniform Circular Motion) there is no need to rely on Tracker to determine the angle that the bob makes with the horizontal. Students can, if they so choose, still record video of the UCM apparatus in motion, but can more easily determine the angle of interest by holding a protractor up to the screen.

Furthermore, as discussed in section 7.3.7, the procedure for lab 7 (Simple Harmonic Motion) had relied on the assumption that students would choose the *z*-component of acceleration as the most interesting of the components. Instead, many groups chose the *y*-component, leading to a period that is off by a factor of two. This portion of the lab should be rewritten to either force consideration of the originally intended axis or consider the accelerometer data from both axes.

Finally, for all of the MyTech labs that used webcam video, it may be worthwhile to investigate the impact of webcam quality on the Tracker analysis. Issues with the camera's temporal resolution were particularly prevalent in labs 8 (Conservation of Mechanical Energy) and 11 (Speed Dependence on the Air Resistance Force).

Using the methods described above, we can reduce negative affect and superfluous MyTech methods in lieu of some more traditional methods.

The last way in which we can improve the existing MyTech curriculum requires a deeper analysis of the temporal graphs produced by the Video Observation Tool. Currently, we have a series of approximately 157 temporal graphs of each group's activities in every lab within the MyTech and traditional sections throughout the three semesters of the study. The data within these graphs is rich, but we are not taking full advantage of them in this project. We could, for example, use the data that produce the graphs to determine common transitions from one activity to the next. For example, perhaps we could determine that the activity tag designating students' collection of data with smartphone commonly precedes the tag designating the TA helping students through a misunderstanding with software. These sorts of data could allow for even more explanation of the issues students encounter in the MyTech and traditional instructional laboratories.

There are many ways in which we can improve the existing MyTech curriculum. First, we can focus on students' comprehension of smartphone data collection methods by incorporating the use of in-app simulations and classroom demonstrations. We can also improve the sources of their trouble-shooting by providing in-app help files and additional MyTech-focused TA instruction. Furthermore, we can reduce the frequency of needlessly complicating the MyTech curriculum by eliminating and improving certain activities in the lab manual. Finally, we can further mine the temporal video data by finding patterns of activities that might lead to additional insight as to the issues students encounter in the MyTech curriculum.

10.2. Furthering the MyTech Study

The MyTech study allowed us to examine many aspects of students' understanding of and attitudes about collecting laboratory data with their smartphones. In addition to continuing to collect data using the methods described earlier, one might also consider further analyzing the quantitative data from previous semesters as well as adding new data sources in future semesters.

As discussed in section 7.2, the video data is an incredibly rich source of information. In this study, we essentially only used the quantitative representation of these data (obtained through the VOT protocol) to compare how much time was devoted to various activities in the MyTech and control sections. We may want to remind ourselves that these data are representative of the *combination* of the data from each group working through each lab. I believe there are still more conclusions to be gleaned from this data.

In addition to time spent per activity, we also have the order in which these activities occurred. It may be interesting, in the future, to improve the VOT so that it also analyzes frequent transitions from one activity to the next. For example, it might be interesting to examine how often the "students working on analysis" tag leads to a TA help tag. These sorts of data might allow us to draw stronger conclusions about what might need further improvements in the labs. As it is currently set up, the VOT does not provide strict frequency counts of activities. This feature might be helpful for determining how frequently data fabrication occurs or how frequently students play with their smartphone in lab. One might also find the temporal analyses of each individual lab of interest. If beneficial patterns of activities can be identified, then perhaps we could use the VOT to determine which labs are in need of the greatest attention.

Finally, if one was to continue the MyTech study, he or she might also consider using an instrument very recently designed by Kuhn and Vogt (Kuhn & Vogt, 2013b) that, among other things, determines the relevancy (or, using their terminology, "authenticity") of smartphone use in physics labs. The instrument (unfortunately, seemingly available only in German (Kuhn, 2010)), is currently being used in four German middle schools on the topic of "vibrations and waves." Perhaps responses to items in the "authenticity" category might strengthen the "real-world connection" results obtained in this study using the CLASS.

10.3. Consideration of an EM-based MyTech Equivalent

Upon hearing of this project, many other instructors and Physics Education Researchers indicated an interest in a series of MyTech labs for the second-semester introductory electricity and magnetism labs. Some researchers have already made strides towards the inclusion of EM-based concepts including diffraction (Kuhn & Vogt, 2012c), oscilloscopes (Forinash & Wisman, 2012a), magnetic field strength (Silva, 2012) and spectroscopy (Sitar, 2012).

In addition, smartphone E&M labs will likely become more popular as the number of smartphone multimeters on the market increases. Unlike the sensors used in the MyTech mechanics labs, the smartphone multimeters are not included in the smartphone's internal sensors. The Voltset (Voltset, n.d.), for example, is a funded Kickstarter project. It is a device (retailing at about $100) that plugs into your smartphone via its USB port. The accompanying software contains built-in equations that allow for easy calculations of current based on a measured voltage and resistance. It also contains a logging feature that collects all of the inputted data into an Excel spreadsheet. The Mooshimeter (Dragon Innovation, n.d.) is another popular alternative. The Mooshimeter was similarly crowd-funded. It is a small, wireless device (retailing at $119) that connects to your smartphone with BlueTooth technology. Like the Voltset, the Mooshimeter has the ability to log data into a spreadsheet. These sorts of devices will allow for a wide array of experimental options.

I believe that the creation of a MyTech lab course for introductory electricity and magnetism is well within reach. The tools are available. We must now consider running a similar MyTech E&M study to determine the impact that such a curriculum will have on students.

11. Conclusions

Results from the MyTech study are promising. Low sample size plagued results from many of the quantitative data sources, including the TUG-K, CLASS and adapted CARS but the richness of the temporal analyses from the coded video data made up for some of these deficiencies. Using results from each of the data sources, we will now attempt to respond to each of the research questions set forth in the study.

1. Do students gain physics knowledge?
   i. How do collaborative learning skills change?
   ii. How do analytical skills change?
   iii. Do students gain a deeper understanding of the role of experimentation?

   It is difficult to say for sure how students' conceptual physics knowledge changes due to implementation of the MyTech curriculum. The Test of Understanding Graphs—Kinematics was initially developed for Microcomputer-Based Labs (Beichner, 1994) and seemed appropriate to use again in the context of smartphone implementation into physics labs. There were no statistically significant differences between responses for the students in the MyTech and control sections on the TUG-K, but MyTech students did experience slightly less normalized gain in this test. In addition, neither the MyTech nor traditional students could explain how the sensors in their labs operated. This was despite the direct instruction given to MyTech students on the inner-workings of their smartphone accelerometer. Furthermore, there were no statistically significant differences in students' frequency of data fabrication between the two sections, indicating roughly equal probability – with other things the same – of students resorting to immoral acts to obtain laboratory data.

The QERL video observation data that emerged from the Video Observation Tool protocol did, however, illustrate statistically significant differences between the two sections. Cassandra Paul's work (2012) on the Real-Time Instructor Observation Tool inspired the creation of the VOT. First, to confirm that the VOT technique was a sensitive measure, we looked for the anecdotal observations of student-TA interactions to emerge from the quantitative video data. Indeed, statistically significant differences materialized in the categories of intra-group conceptual discussion, intra-group procedural discussion, discussion of lab concepts with TA, class discussion with TA, WebAssign use, reading the manual, intra-group chatting, chatting with the TA and data fabrication. These data were consistent with qualitative observations made of the TAs' behaviors in the lab. Once the VOT technique was established as reliable, we could seek out statistically significant differences in other categories. MyTech students, for example, spent less time recording with physical equipment, asking the TA about physical equipment, talking to the TA about software malfunctions (in Fall 2014, but not Spring 2014) and chatting with the TA. On the other hand, MyTech students spent more time preparing the laboratory equipment, intra-group conceptual discussions, asking the TA about misunderstandings regarding software, asking the TA about misunderstandings regarding analysis, recording with software, WebAssign usage, reading the manual, intra-group procedural discussion and (clearly) answering questions only asked of the MyTech sections. Students in the MyTech lab spent 18 minutes more, on average, per lab than their traditional counterparts.

2. How do students' attitudes about laboratory experience change?
   i. What is the evolution of affective and cognitive predisposition toward physics?
   ii. Does their self-confidence improve?

The most promising and exciting differences between the MyTech and traditional lab students occurred to their physics affect. QERL observation allowed me to directly witness students' own enthusiasm over the course. Occasionally, students in both sections would become confused and request TA guidance. Unfortunately, the TAs were much more experienced in troubleshooting the traditional labs than the MyTech labs, and so the students in the MyTech labs struggled somewhat.

Still, the results from the Colorado Learning Attitudes about Science Survey (Adams, 2005) for the MyTech labs are promising. Overall, the attitudes among students in the MyTech labs barely change whereas those in the control group become less expert-like. The largest change occurred in the "real world connections" category, in which MyTech students respond more favorably and traditional students respond more unfavorably. It was posited in section 8.3 that this might be due to MyTech students' ability to "insert themselves" into the lab. Furthermore, unlike traditional students, MyTech students demonstrated a strong positive shift in thinking about which physics ideas apply to the problem while solving it, perhaps indicating that MyTech students are more likely to develop some forethought about their labs prior to running experiments. Notwithstanding, traditional students experience less negative shift than MyTech students in their responses to a statement about feeling satisfied until they know why something works the way it does.

Furthermore, as discussed in section 7.3, students' general enthusiasm about the lab course was also encouraging. Students seemed excited to see a connection between the physics concepts they learned about in class and the capabilities of their own smartphones. One student even exclaimed, "SCIENCE!" excitedly. In addition, even students in the traditional lab sought out their smartphones for their stopwatch and calculator abilities. Their actions were unprovoked, and suggest that they would have also eagerly adopted the use of smartphones in their physics labs.

We could have perhaps improved MyTech students' attitudes even more by changing our expectations to a level more appropriate of students in their first college physics course. Even by the end of the course, many students still struggled to understand what axis on their smartphone they should graph. To this end, I would recommend that instructors provide the axis of interest to students in introductory classes and consider a deeper discussion of this topic at a more advanced level. These new suggestions parallel the guidelines set forth by the AAPT this past year (Kozminski, et. al, 2014).

3. Will students use the devices outside of the lab?
   i. Do they become more aware of everyday physics applications?
   ii. What is the impact of having students connect in-class physics knowledge with out-of-class physics knowledge?

The post-semester survey of technology usage reveals a few students' self-reported activities with the device outside of the formal laboratory environment. One student claimed to have measured acceleration while longboarding. Another suggested that he performed a very informal experiment to test out the app while walking and "moving [his] arm in a variety of ways."

The new MyTech app will allow us to collect more data about where and when students use the app. After installing the app, it has the potential to request access to students' "core location." (Students would, of course, "opt-in" to this feature and thus we would only be gaining that information from those that allow us to do so.) This will enable us to collect data analytics about app usage outside the lab.

In addition, the adapted CARS presents us with some interesting data regarding technological anxiety. Students in the traditional sections exit the course with slightly more negative views of their computers and students in the MyTech sections exit the course with slightly less positive views of their smartphones. These data seem to somewhat contradict the differences in students with and without MyTech lab experience. Free responses to students' thoughts on smartphones in physics labs indicated that post-semester MyTech students viewed their experiences as more positive (63%, n = 19) than those with no experience (52%, n = 52).

4. How does the implementation of these electronic devices affect the performance and attitudes of female physics students?
   i. Do their attitudes about physics change?
   ii. Is there any affect on their performance?

   At the outset of this project, we had hoped to gain more data regarding women's use of smartphones in their physics labs. Unfortunately, the quantitative data from Meredith College proved too sparse to be meaningful. Instead, the three labs performed at Meredith acted more like a feasibility study. In addition, we heavily relied upon the comments of the all-female population at Meredith to produce a series of criticisms of the pre-existing SensorLog and AndroSensor apps.

One might also argue that the MyTech project answered questions beyond the scope of the research questions initially set forth. In addition to the quantitative data produced by students' test responses and their qualitative comments about the labs, Outcome 1 (the creation of a software tool for qualitative education researchers) allowed for the characterization of the *nature* of students' behavior in the lab. The creation of the Video Observation Tool clearly facilitated the comparison of students' activities in the MyTech labs and the traditional labs, but the data produced by the tool could also be used to answer broader questions regarding students' equipment usage during physics labs. This data could one day complement further research into student-equipment interactions in instructional laboratories.

Overall, we believe that the results of the MyTech study are promising. We showed that their kinematics skill gains are comparable with the TUG-K and that the MyTech students experienced slightly increased anxiety with their smartphones and control students experienced slightly increased anxiety with computers. When asked about their thoughts on smartphone usage in the class, however, students with experience in the MyTech labs were more likely to respond positively. According to the results from the Equipment Survey, neither group could accurately describe how the electronics they used collected data. The attitudinal results from the CLASS showed nearly no change over the course of the MyTech students' semester but a slight shift toward less expert-like responses over the course of the semester for the traditional students. Specific categories of the CLASS, like "real world connection" and "sense making" showed some positive strides in the MyTech section as compared to the traditional section. On the whole, we believe that, with proper implementation, students could indeed benefit from the use of their own personal smartphones as data collection devices in introductory mechanics labs.

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APPENDICES

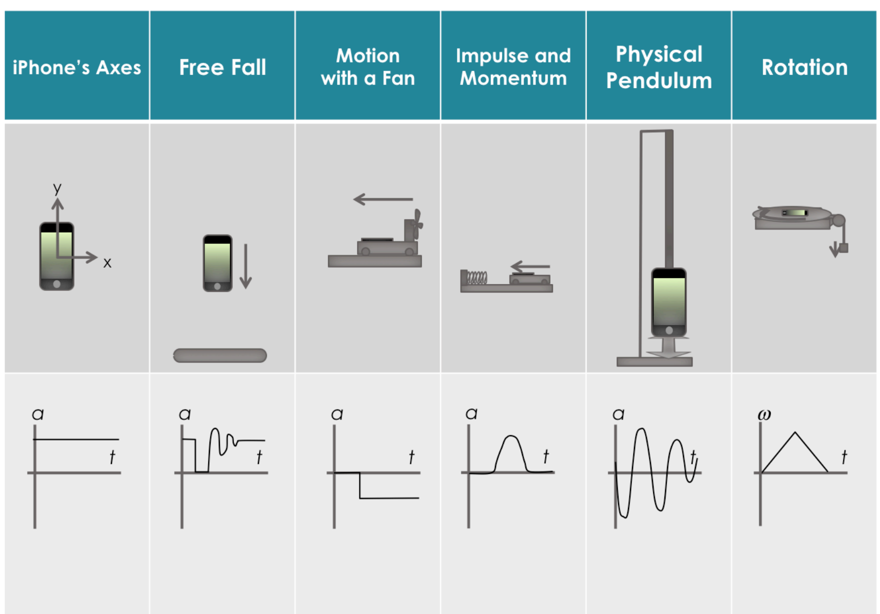
Appendix A: MyTech TA Lab Manual

MyTech TA Lab Manual

The purpose of this lab manual is to familiarize TA's with common problems and solutions that they might encounter uniquely in the MyTech labs. This manual is not meant to be a stand-alone document, but instead, *this should be read in conjunction with a traditional TA Lab manual.*

An Introduction to the MyTech Labs

Today's smartphones have the ability to measure their own motion in physical space. We will take advantage of this capability of students' own smartphones and use them as data collection devices in lieu of the traditional equipment. The labs have been altered as minimally as possible in an attempt to achieve the same benefits of traditional labs by implementing these smartphones. You may get a feel for the ways in which some of these labs have changed by glancing at the summary of lab curriculum below.

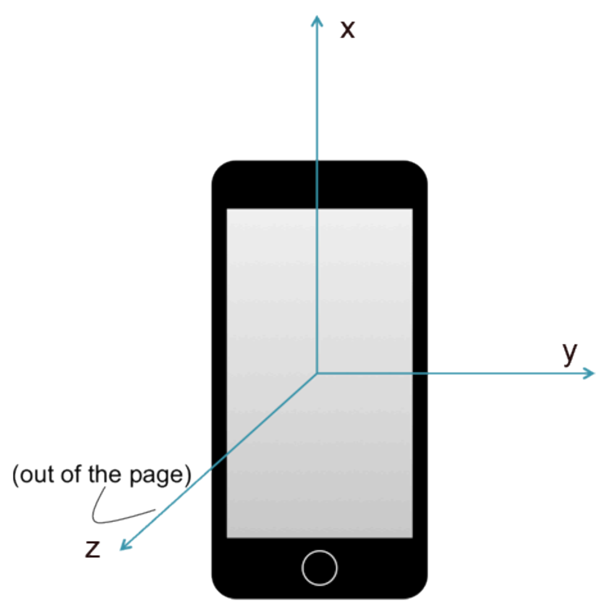


Smartphone Sensors and How to Explain How Their Work

The vast majority of smartphones manufactured after 2009 contain both an accelerometer and a gyroscope that can measure the linear and rotational motion, respectively. We will use apps to gain access to the raw data produced by these sensors.

The Smartphone's Axes

The axes for the accelerometer and gyroscope measurements are fixed to the phone, as illustrated below.

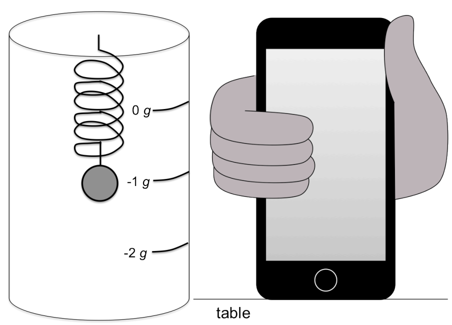


Note: iPhone and Android phones have inversed the signs on their accelerometers. Be aware that a positive acceleration on an iPhone is displayed as a negative acceleration on an Android phone.

Measuring Linear Acceleration with the Accelerometer

The vast majority of the labs in the mechanics curriculum make use of the accelerometer. We can think of the accelerometer as a ball attached to a spring.

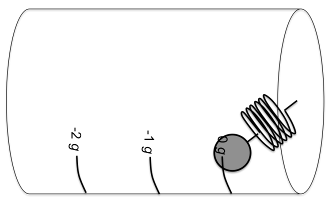
Note: I **strongly** encourage you to use this metaphor throughout the course. It will make it easier for the students to design their experiment if they understand what the accelerometer is measuring.



As in the figure above, if the phone is oriented with the bottom edge making contact with a table (as illustrated in the second figure above), the “ball” in the ball-and-spring model is pulled down by the force due to gravity, and the accelerometer along this vertical axis of the phone reads -1g.

Note: Students are not accustomed to reading acceleration graphs in units of g. You may need to explain to them that 1 g = -9.81 m/s^2.

If, instead, the phone is rotated 90^{o} so that the right edge makes contact with the table, the spring compresses to its relaxed length and the accelerometer along that vertical axis reads 0*g* (as shown in the diagram below).



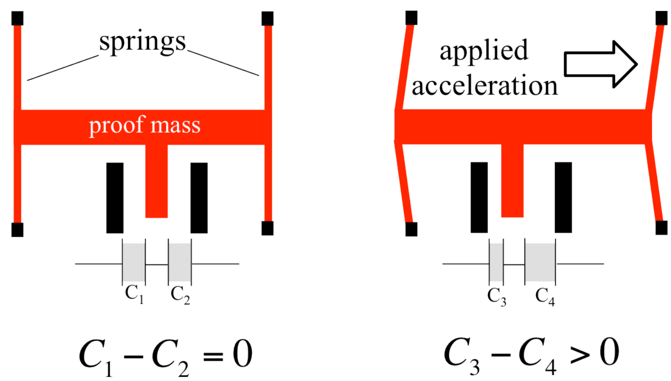
Now, if you reorient the phone to its original position (with the bottom edge making contact with the table) and jerk the phone upward, you would expect that the ball (due to inertia) would move as little as possible, thus expanding the spring. The accelerometer would read <-1*g*.

Conversely, if the phone is dropped and experiences free fall, the phone and the "ball" (in the ball-and-spring model) both experience the same force due to gravity, and so the accelerometer reads 0 while in free fall.

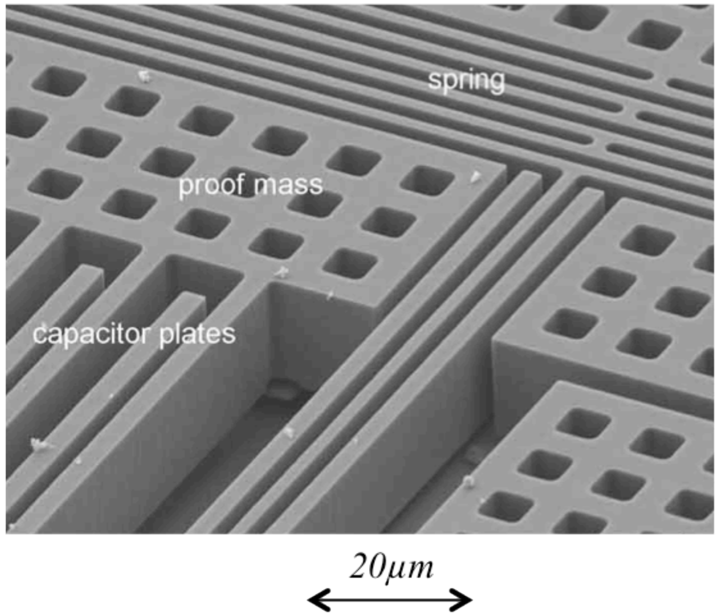
For advanced students and your curiosity

> *Note:* You will find more detailed information on the accelerometer chip below. This information is likely outside the realm of the typical PY 205 student.

The accelerometer chip itself is an implementation of this ball and spring model. Instead of using an actual ball and spring, the chip has been "carved" out of silicon. The chip itself is just a fancy three-plate capacitor. The plates of the capacitor move as the phone moves, thus changing its capacitance.



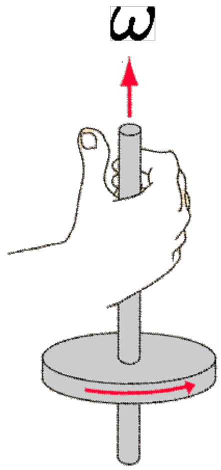
The diagram above demonstrates how the “ball” in the simplified model is replaced with a proof mass that is bound to the fixed accelerometer chip only by spring-like silicon arms. Motion and orientation of the device are converted to a digital signal using variable capacitors, where the position of the “teeth” attached to the proof mass relative to the accelerometer housing determines the current through the device. Software converts the current output to an accelerometer reading. The photo below (Chipworks, 2014) shows the actual accelerometer chip.



Measuring Rotational Motion with the Gyroscope

The gyroscope is trickier to understand.

It suffices to say that the gyroscope measures rotational data. If we place the phone on a turntable (as in the photo below) and allow the turntable to rotate freely, the phone will effectively use the right-hand rule and measure a rotational velocity, ω, in the z-direction.

Second figure adapted from http://hyperphysics.phy-astr.gsu.edu/hbase/rotv.html

For advanced students and your curiosity

If you (or your students) are interested in how the gyroscope works, you may want to check out this short YouTube video: http://www.youtube.com/watch?v=zwe6LEYF0j8

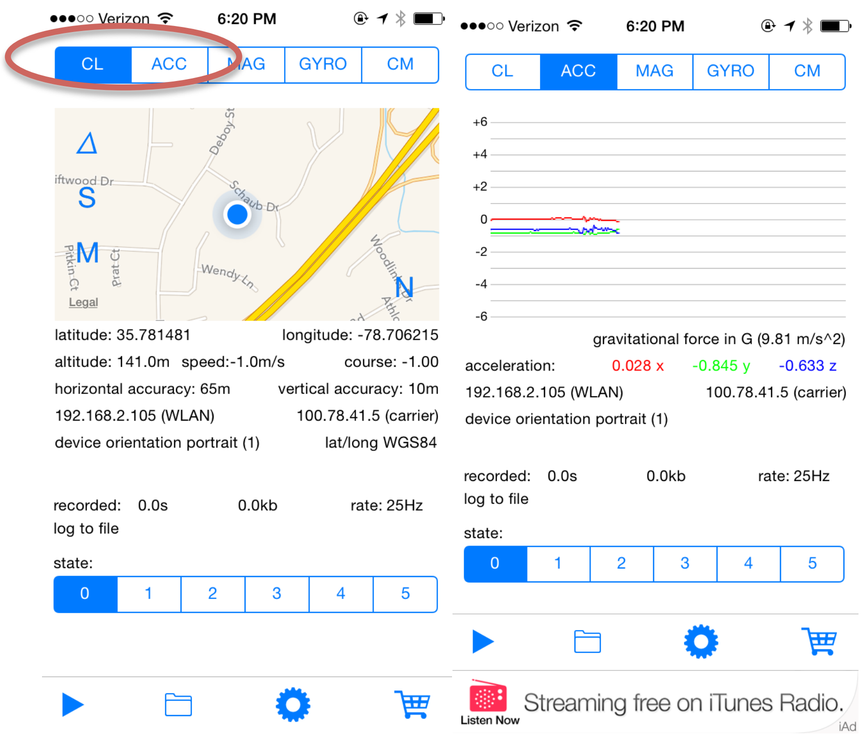
An Introduction to Data Collection Apps

We have been using two free apps in the MyTech Labs. One unified app (to be titled "MyTech") is in development and should be available for free download by Summer 2015.

SensorLog for iOS

You may download SensorLog for the iOS in the App Store.

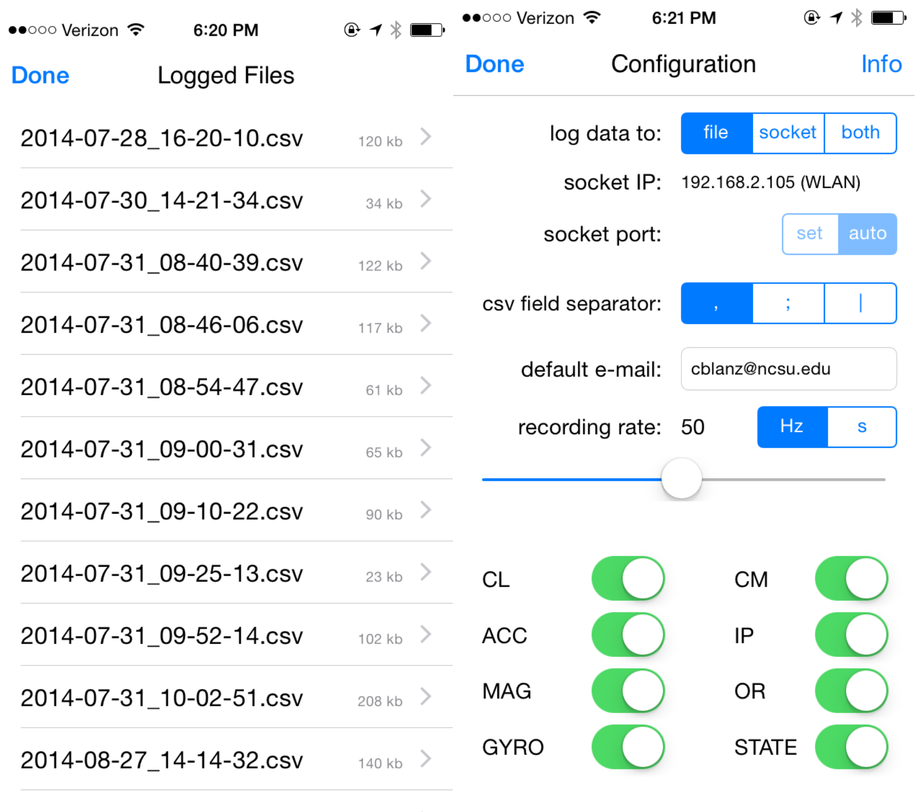
The default opening screen of SensorLog is the "Core Location" (CL) mode. You can access the accelerometer (ACC) and gyroscope (GYRO) modes (both circled) at the top of the screen.



The accelerometer screen (second in the figure above) displays the raw accelerometer readings at all times in both numerical and graphical forms. There is no way to pause or "rewind" the graph.

Additionally, they can record the data for future analysis in Microsoft Excel by pressing the play button (▶) at the bottom of the screen. They can stop recording by pushing the pause button (❚❚).

They can then send the saved data file to themselves by pushing the browse button ( ). They will be shown the list of all files that they've ever recorded. The files are automatically named with a time and data stamp, and the newest file is at the bottom of the list. By selecting the file, they are brought to an email screen, where they simply need to change the email address to their own.



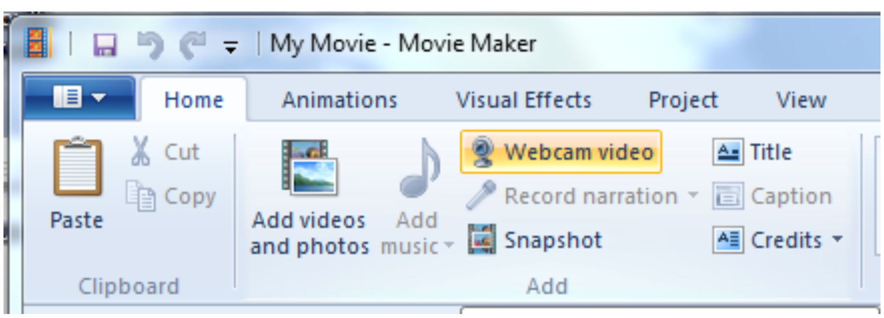
Additionally, from the accelerometer/gyroscope screens, students can also push the settings button (⚙). They will be brought to the second screen above. Students can enter their own default email address. The most important aspect of the settings mode is the access to the **recording rate**. Students must select 50 Hz for well time-resolved data. If they want, they can also de-select everything but ACC and GYRO for simpler Excel files.

Tracker Video Analysis

Unfortunately, the smartphone's ability to measure acceleration is limited. One might be tempted to integrate the acceleration data to determine the velocity data, and perhaps even integrate again to get position data. Unfortunately, the accelerometer will not allow this without velocity and position drift. Thus, we must look to other options to obtain velocity and position data.

To fill this gap, we will record the motion of objects in the lab with a computer webcam and then we'll analyze the results using free video analysis software, Tracker. You may download Tracker here: https://www.cabrillo.edu/~dbrown/tracker/

1. First, students will be asked to position the camera in way that will allow them to analyze all of the motion of interest. **The webcam should not be hand-held.** Any inadvertent movements of the webcam will lead to inaccuracies in the data.
2. To record video, students will open Windows Movie Maker (Start Menu > "Movie Maker"). They will need to press "accept" on the agreement upon the first opening.
3. At the top of the screen, they will push the "Webcam video" button.

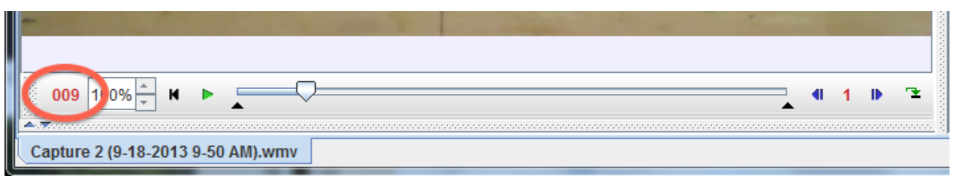


Note: The webcam takes a moment to register. This is especially true if students have only just plugged in the webcam. Students may have to wait up to a minute for the webcam's view to appear in the Movie Maker window.

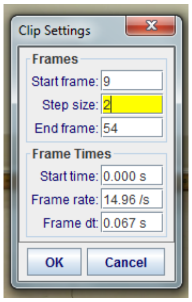
4. They will push the record button to begin recording, and the stop button to stop recording. They will immediately be prompted to save the video. They should note where they save the video.
5. They should close out of Movie Maker (and press "no" when asked to save changes to My Movie).
6. Then, they will open Tracker and open the File Menu. Then they select File | Import | Video… and open their video file.

Note: If they receive a message that tells them "Some frame durations differ from the mean by more than 20%...", press "OK."

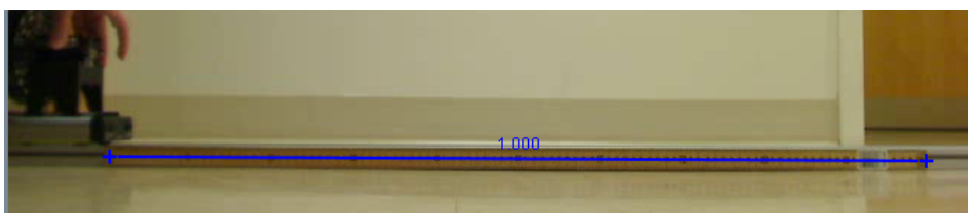
7. They now must limit the movie to only the frames they want to analyze.
    a. Using the arrow keys, they should navigate to the first frame that they want to analyze. They ought to note what frame they will start with.



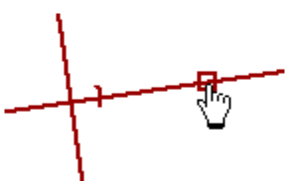
    b. Then, using the slider bar, they should navigate to the last frame they want to analyze, making a note of this frame number as well.
    c. They should click the "clip settings" button on the toolbar. 
    d. They should enter in the start and end frames and change the "step size" to 2 (so that they will have to analyze fewer frames). Click "ok."



8. Click the “calibration” button and select “calibration stick.” 
9. They should drag the ends of the calibration stick to something that they know the length of (such as a meterstick or part of a meterstick). They then click the readout to select it and enter the known length (without units). For example, students might use a meterstick and enter in “1” (so that the “meters” is implied).

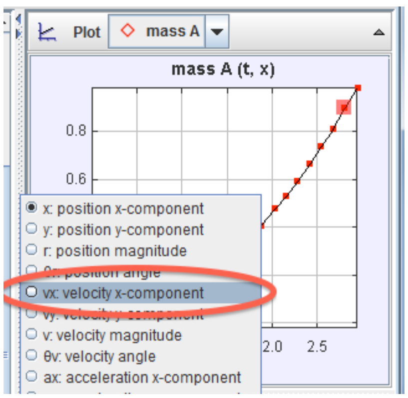


10. They’ll then click the “axes” button to show coordinate axes. 
11. They should then drag the origin to the initial position of the object. They can also rotate the axes slightly by dragging the *x*-axis around.

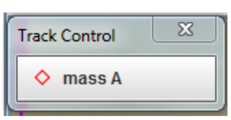


12. They ought to click the "create" button and choose "point mass." 

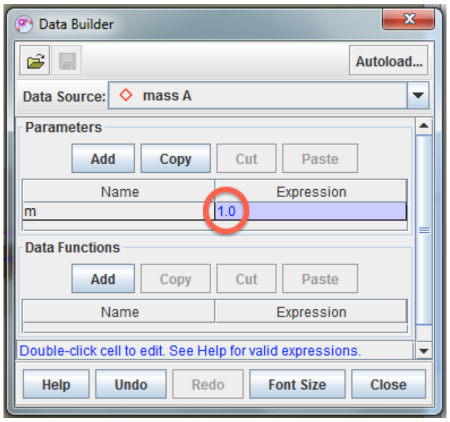
13. To track an object, they will mark its position on every frame by **holding down the shift key** and clicking the mouse as the video automatically steps through the video clip. (Be sure they don't skip frames, and that they always track the same part of the object in motion.) *Note:* Stress to students that **this is the most important step** because it has the greatest influence on the accuracy of their results.
14. A plot of the motion will automatically appear on the right side of the screen. Students can choose what is displayed on the vertical axis of this graph by clicking the current label and choosing among the available options.



15. If they choose "momentum" among these options, they should first enter the mass of the object whose motion they are analyzing. They can do this by clicking "mass A" in the "Track Control" panel, and selecting "Define…"



17. In the *m* parameter, they can enter the mass of the object in kg.



18. To change what data appears in the "table" window, they can click the word "table" to open a menu for "Visible Table Columns." They can choose from the available options there.

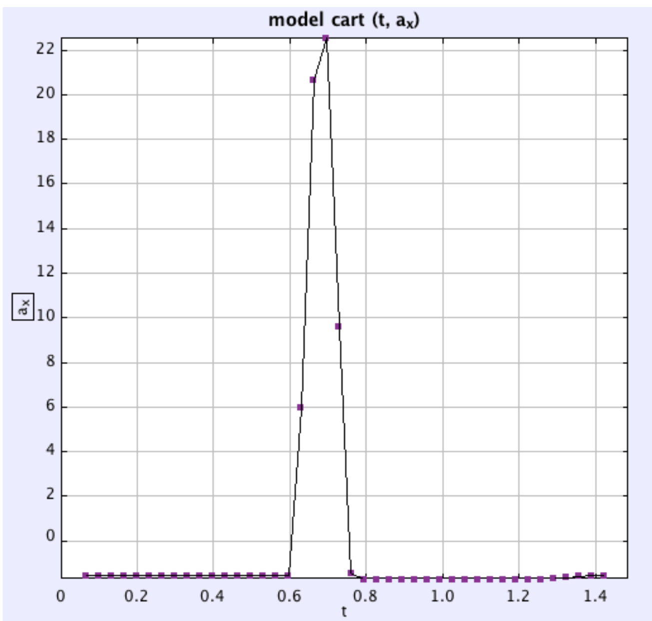
Lab Keys

Note: Make it clear to students that they will receive full credit for their **predictions** *as long as they make an effort*. These prediction questions often come in the form of sketched graphs. They need only be able to support their prediction with reasoning. The graph need not be accurate. They do not need to re-upload sketches after discovering that their initial predictions were incorrect. **Try to help them** with their predictions.

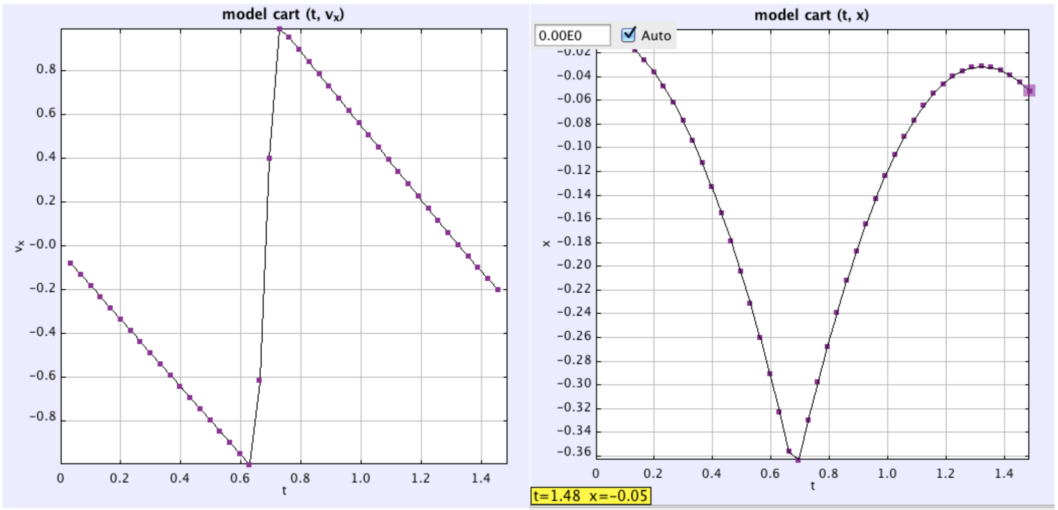
Lab 1: Discovering Smartphone Axes

The purpose of this lab is for students to become familiar with the smartphone apps and Tracker analysis software that they'll be using in these labs. They are asked some basic questions about the app. They are also asked to predict what their accelerometer graph will look like. **Try to help them with this**, and guide them through the ball-and-spring model described in the "Measuring Linear Acceleration with the Accelerometer" section above (page 265).

The acceleration versus time graph that students *should* predict looks like the figure below. Do not take off points if they get it wrong, as long as they can provide reasoning for their sketch.



The resulting velocity and position graphs should look like:

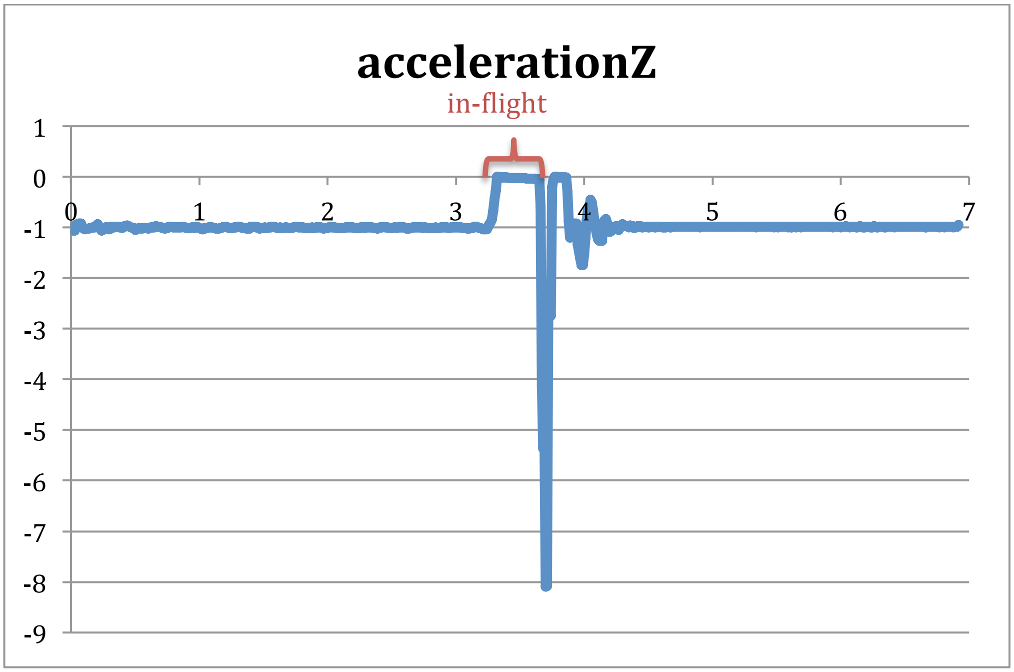


Lab 2: Free Fall

For the first time, students are asked to record data with their smartphone and analyze it with Excel. Students will drop the phone on their pillow. They will record acceleration along the *z*-axis. Before they drop the phone, the accelerometer should read -1*g*. While the phone is in free fall, the acceleration should jump up to 0*g*. For more information on this, you should reread the section titled “Measuring Linear Acceleration with the Accelerometer.”

The only real "tricky" part to this lab is having the students learn how to email the data files to themselves. You may want to review the section titled “An Introduction to Data Collection Apps.”

Some sample data from the free fall lab:



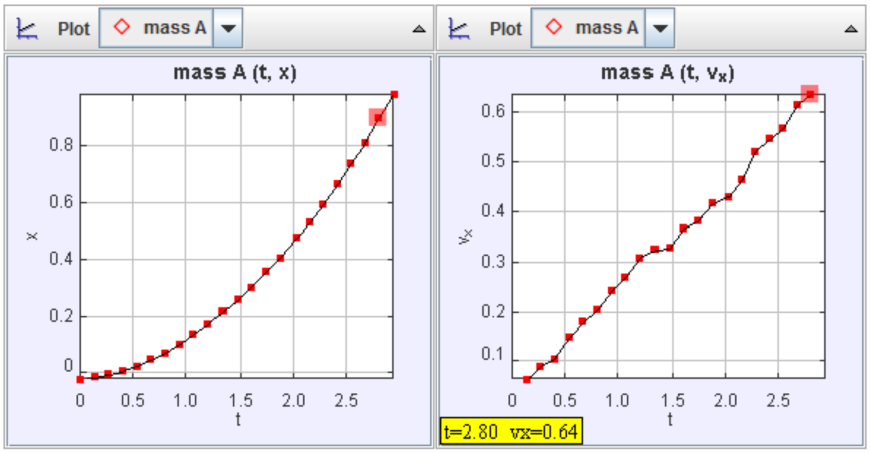
Lab 3: Uniformly Accelerated Motion

There will be at least two weeks between this lab and their first lab, where they were familiarized with the Tracker video analysis software. This is also the first lab where they will be asked to track the motion of the cart with Tracker.

In short, students will not be using their smartphones in this lab, and are only tracking the motion of the cart using Tracker. You should review the section on "Tracker video analysis."

- Make sure students don't hold the webcam in their hands. Be sure it is stationary. Otherwise, the Tracker graphs will be meaningless.
- Be sure that they track the same *part* of the cart throughout the motion (whether it's the front bumper, the center, etc.) They should take their time here, as this is perhaps the single most important step for accuracy.

- Make sure that they know to stop the cart from hitting something.
- You may want to consider showing them idealized version of *position vs time* and *v_x vs time* graphs (see below).

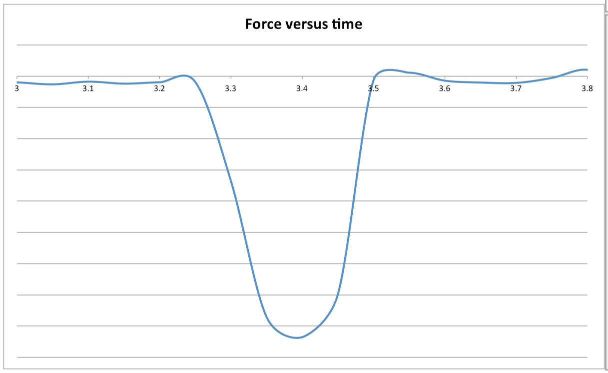


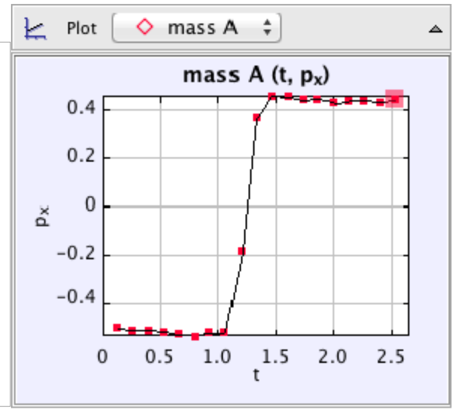
- They may need help using the triple-beam balance to get the mass of the fan-cart. I can show you the "trick" for measuring large masses like these before class on Friday.

Lab 4: Impulse and Momentum

In this lab, students will be using Tracker *and* their smartphones, and comparing the results from each. Try to be sure that they don't "look ahead" in the instructions too much, as they will find the answers to their "predictions" in there! (I'd like to see if they're able to come up with them on their own.)

Here are the *F* versus *t* and *p* versus *t* graphs that you should expect to see:

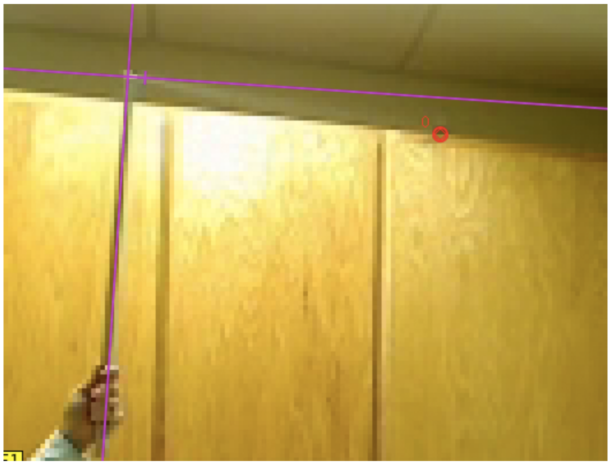




Lab 5: Uniform Circular Motion

This lab is fairly similar to the traditional section, and students won't use their smartphones at all – only Tracker.

In fact, the only section where they use different equipment is in the last section, where they'll be asked to record the motion of the apparatus to find the angle theta. This isn't a perfect system since the string is actually pretty hard to see in the video, but it ought to be a better approximation than holding up a protractor in the air.

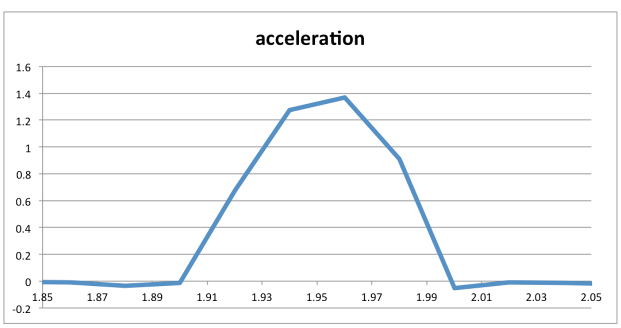


Lab 6: Impulse, Momentum and Energy

In this lab, students will use their smartphone to measure the force from the spring on the smartphone-cart system. They'll use Tracker to measure the velocity. Then, just as in the traditional lab, they'll compare the two sides of the equation

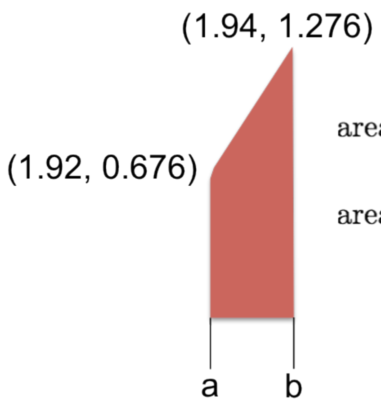
$$\int F\,dt = \Delta p.$$

The accelerometer graph should look similar to the one that they obtained in lab 4.



Students may need some help using the trapezoid rule with their accelerometer data.

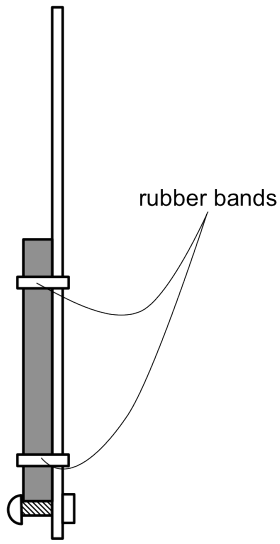
You may want to review the diagram below:



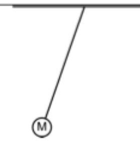
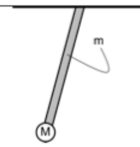
$$\text{area} = (b - a)\left(\frac{f(a) + f(b)}{2}\right)$$

$$\text{area} = (1.94 - 1.92)\left(\frac{0.676 + 1.276}{2}\right) = 0.0195$$

Lab 7: Simple Harmonic Motion

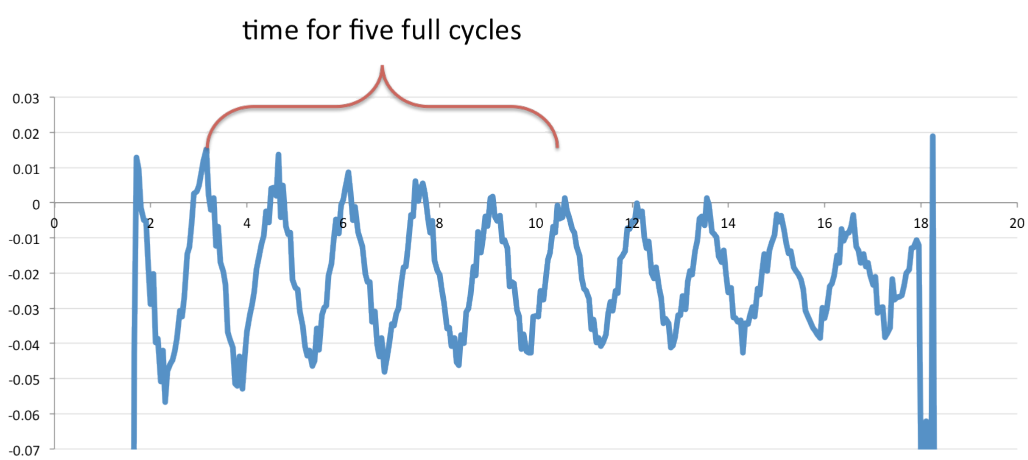


There are four sections of this lab. The first three (Hooke's Law, period of a spring pendulum, and period of a simple pendulum) do not use the smartphone nor Tracker. The last section (the physical pendulum) uses the smartphone as the "bob" on the pendulum. The mechanism that they attach their phone to has some mass, and thus it is not a simple pendulum, but a physical pendulum. (In a simple pendulum, all of the mass is only at the bottom of the pendulum in the bob, but in a physical pendulum, mass is distributed continuously along the entire pendulum length.) They will use the accelerometer in their smartphone to determine the exact period of the pendulum. They will then calculate *g* again. The equation for the period of a physical pendulum just has **an extra multiplicative factor** in it that I've called F, so they will have to use THAT equation (not the normal simple pendulum period equation) to determine *g*.

simple pendulum		$T = 2\pi\sqrt{\frac{L}{g}}$
physical pendulum		$T = 2\pi F\sqrt{\frac{L}{g}}$

Here, the multiplicative factor, $F = 0.88$.

The **trickiest part of the lab** is in determining the period from the accelerometer data in Excel. Students are often off by a factor of approximately 2 because they do not consider that one full cycle is one full up and down "V" in the accelerometer graph.



Lab 8: Conservation of Mechanical Energy

The first two parts of the lab (solving the motion of the ball kinematically and using energy concepts) are components of the traditional lab. The MyTech version simply adds on one additional component where they verify the final velocity using Tracker.

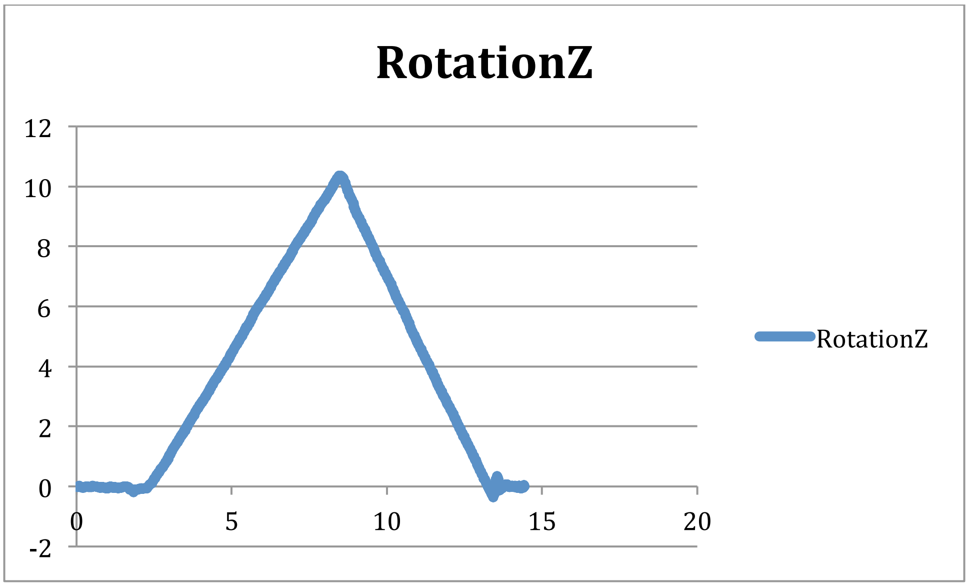
Some students become confused about where to position the webcam when they take the video. Since they are interested in the velocity of the ball just as it leaves the ramp, they should position the webcam so that they can see the trajectory of the ball **slightly before and slightly after exiting the ramp**. They really only need to analyze three frames (immediately before, during and after leaving the ramp) to obtain the necessary data.

Lab 9: Angular Impulse and Angular Momentum Change

This lab runs somewhat similarly to the traditional labs. We have replaced the photogates in the traditional lab with special turntables that students can strap their phone to with a rubber band. The conceptual aspects of the lab are the same, but students will be able to *directly* measure ω (instead of using a v_{tan} to get omega).

Students will *not* use the accelerometer for this lab. This is, in fact, the first lab we are using the smartphone but *not* the accelerometer. Instead, **they will use the gyroscope**. Based on survey results, students are super confused about the differences between the accelerometer and the gyroscope. **I would recommend telling them that an accelerometer measures *linear* motion and a gyroscope measures *rotational* motion.**

Since the phone is rotating in the *x-y* plane, ***ω* should be measured along the *z*-axis** (from the right-hand rule). Sample data is provided below:



Lab 10: Young's Modulus

There are no changes to this lab from the original lab.

Lab 11: Air Resistance

This lab is very similar to the traditional version, but with one additional section where they will be asked to repeat the experiment with Tracker. They are then asked to compare their results from Tracker to their results from the traditional stopwatch.

Troubleshooting Common Errors

Why are the accelerometer values always changing when I keep the phone still?

Both apps report more digits than are probably helpful to students. Thus, the accelerometer appears to be *incredibly* sensitive to any motion. Students should focus on the ones and tenths places of the accelerometer read-outs.

Where is my data?

There are two possible answers:

1. They did not record data. They should review practices for recording.
2. They recorded data, but cannot find the data. You can help them browse to their most recently recorded file.

How do I change the recording rate settings?

Click on the "settings" button, and choose a faster recording rate (switch to Hertz and increase the number).

How do I email the data?

Review the browsing and emailing portions of this manual.

How do I graph the data in Excel?

Select the two columns in question. This is often "record time" and some axis of the accelerometer by control-clicking. Choose "insert" and "scatterplot."

How do I know what columns to choose?

Encourage them to consider the ball-and-spring model to determine which axis would experience the greatest change in acceleration during the recorded duration.

I have too few data points in Excel! What do I do?

Increase the record rate by choosing “settings” and selecting a faster recording rate (by increasing the number the Hertz).

Appendix B: Results from the Teaching Beliefs Interview

Adapted Interview Question Guide (Adapted from Luft & Roehrig, 2007):

(1) How do you maximize student learning in your laboratory?

(2) How do you describe your role as a laboratory instructor?

(3) How do you know when your students understand?

(4) In the laboratory setting, how do you decide what to teach and what not to teach?

(5) How do you decide when to move on to a new activity in your laboratory?

(6) How do your students learn science best?

(7) How do you know when learning is occurring in your laboratory?

(8) Did you prefer to teach the smartphone labs? Or the control section? Why?

(9) What are your final comments?

- **Regarding the Teaching Beliefs Interview (TBI):** Over the course of the study's three semesters, three different Teaching Assistants were utilized. All three are graduate students in NCSU's physics departments, however their teaching experiences varied widely. In an attempt to assess the TAs' pedagogical beliefs, all three were interviewed using the Teaching Beliefs Interview (TBI). The TBI has been used in different settings (LePrevost, Blanchard & Cope, 2013; Addy & Blanchard, 2010) but was created for the purpose of capturing the beliefs of secondary science teachers with varying levels of experience (Luft & Roehrig, 2007). All three of the TAs were interviewed on the same day (at the end of the third semester of the study), so some of their memories of the MyTech curriculum were clearer than others. When requested by the TAs, questions were clarified and reworded so as to more closely incite discussion of the TA's behavior in lab. Responses after such a clarification were not analyzed.

- **Regarding the rating methodology and IRR:** The papers do not go into a great deal of detail as to how TAs' individual responses are categorized. As a result, Bin, another PER grad student, and I took it upon ourselves to construct a standardized method for coding the transcribed interview data. We attempted to code, on a continuous scale from 1 (traditional, teacher-focused methods) to 5 (reform-based, student-focused methods), TAs' individual thoughts within their responses to each question. After discussion, we reached 100% agreement on what were considered TAs' individual thoughts as well as the numeric value with which they should be coded. We then averaged the numeric values within a question and assigned a total "score" to the TA's response to each question. Responses to questions 0, 8 and 9, when provided, were not coded as the responses did not relate to any of the seven "beliefs questions" set forth in the original Teacher Beliefs Interview.
- **Regarding TA 1:** Bin found TA 1, an anonymous international grad student, to hold beliefs similar to other international TAs (through anecdotal evidence). Specifically, he found it very representative that TA 1 was very humble in his approach with students and that he considered himself more of a learner than a teacher. According to Bin, TA 1 appeared to be "half humble, half [of] low self-esteem," primarily due to the TA's lack of

communication abilities. Bin suggested that international TAs tend to have a high degree of physics understanding and a relatively low handle on the language. Thus, international TAs are often surprised at what the students don't know. As a result, international TAs tend to observe and stand back to allow for clearer observation of the students and their misconceptions.

TA TBI Results

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Total	Std. Dev.
TA 1	1.5	3.25	3.0	2.0	3.0	4.0	3.3	**2.86**	**0.84**
TA 2	3.0	3.0	3.0	1.0	1.0	2.5	1.0	**2.07**	**1.02**
TA 3	3.0	4.0	2.0	1.8	1.0	2.0	5.0	**2.69**	**1.40**

TA for Semester 1

Q	**Transcript**	**Agreed**	**Bin**	**Colleen**	**Total**
0	0:00: COLLEEN: I'm just going to put that there. So I just have a few questions. There's nine questions total and they're basically just about your TA experience and stuff. So how long have you not been a TA? TA: Not been a TA? One year. COLLEEN: OK, so it's been a while! Alright, well let me just start with the first question.				
1	00:34: COLLEEN: OK, so thinking back to your TA experience, how do you maximize student learning in the lab? TA: Um, including the preparation before it? COLLEEN: Yeah.	1	1	2	**1.5**

	TA: Basically I—before each time I teach, I try to do it myself. I try to put myself into their positions, and uhh, think about that if I, you know, didn't have anything except the instructions, […] what kind of a sense of understanding about the instructions would I have? Relate the material with their knowledge. Once I found the problems, I try to think about the solutions about them. Of course, we can always find solutions to those questions. It's a problem of how to *explain* them. Basically I try to use graphs and simple examples to illustrate them. I think so. Sometimes I will just prepare some basic questions about their backgrounds, about physics material of the experiments. And, uh, try to find out if they can manage to succeed or if they could understand […].	2	2		
2	02:44: COLLEEN: Ok, so how would you describe your role as a lab instructor? TA: Actually, to me, I am not just an *instructor*. Sometimes I am the *learner*. It's … I am not a native speaker in the first place, and I need to learn how to, well communicate with them and properly express myself, and understand *their* questions*.* And also, being a foreign graduate student, my educational background is some kind of different. So, I need to get myself adjusting to their learning habitat, how to use all kinds of different instrument[s], like calculators. Typically, back in China, we don't use that very much. We always like to do calculations by brain. COLLEEN: Wow, ok. TA: So, it's kind of a difference in … so, with this, or without this, it will just form a different kind of thinking habitat. […] Also, just instructing them, I am not just explaining things to them. Also, I need to learn how they—how *well* they can learn from my instructions, and also I need to learn about them. You know, students are different. Some of them are smart; some of them, they don't like physics very much.	3 2 3 5	3 3 5	3 2 5	**3.25**

	COLLEEN: Right. Haha, there's a lot of those. TA: I need to know if they have some troubles with their math background or they don't like science at all, or something else. Yeah, something like that.				
3	05:37: COLLEEN: So how do you know when the students understand? TA: Ok. So, the most of the time, I just collect information from their understanding about the questions. Basically, most of the time, I don't really have time for each of them to ask them 'if you understand this or not.' I just come and go. So basically when they ask questions about these questions, I ask them to explain the questions themselves so I can know if they truly understand what the question is asking them about. And also, I can find out if they can relate the questions to their knowledge right now. And so after I explain the solutions to them, or give them clues that will lead them to use evaluation tools, their experimental tools.	2 4	2 4	2 3	**3.0**
4	07:09: COLLEEN: So when you're in the lab, how did you decide what you were going to teach at the beginning, and what you're not going to teach? TA: Mmmm… so, that's – actually, that depends on different sections. In some sections, there are really a lot of people that have trouble with the lab materials. They can do it very fast, so if that's the case, I just explain the materials. So, to let them know some knowledge beyond the experiment but related in the materials. But for some sections, I—there are some people they think are not – […] that might not finish in time. So I do not have the time, and I do not talk too much before the lab. I just give them clues – what would be the most important fact in this lab and I try to help them […]	3 1	3 1	3 1	**2.0**
5	08:40: COLLEEN: How do you decide—this is kind of a hard question for our labs—but how do you decide when to move on to a different				**3.0**

	activity? So, if you see maybe students are stuck or something, how do you decide when to push them forward? TA: Yeah, that is a little tricky. I would just stand by there for a while to see if they can get something to get themselves in the program. If they cannot, and they will totally mess [up] the lab, I will try to stop them. Because sometimes people from other area[s] […], do just mess [up] the lab, that there's some kind of related knowledge based off of this physics, but actually not. If so, I stop them, and that way they don't go on forever and ever.	3 3	2 4	3	
6	10:01: COLLEEN: Yeah, we've both seen that before. So how do you think that students learn physics best? TA: Actually, I don't think all of them can do that. Some people, they will not learn very much from the physics lab and I think that's—that should be normal, and since we have the scoring points and skills there are always people bad at that. I think as long as there are half of them—half of them—that can learn physics, so basically when they know what [they] should do—Sometimes the instructions say that they have step one, step two, step three. So umm, some people who really know physics, they will know that when I do step one, step two, the steps really work in just clearing the mind. They should not just follow the instructions. Instructions is [sic] just for their records, and they can just use them to verify whether they are following the right path or not. So, if they can just do that—not just follow the instructions—I think they learn.	3 5	3 5	5	**4.0**
7	11:51: COLLEEN: How do you know when students are learning in their lab? TA: They will ask questions. They will ask questions beyond my imagination. COLLEEN: Oh, ok. In a good way—or? TA: Most of the time they are asking just physics-related questions beyond these materials. I think	5	5	5	**3.3**

	[…] Sometimes those people still ask the lab really good questions. I know they are learning because there is some kind of group that always gets stuck in the labs but they are trying to know why they are doing this. After I explain [to] them, <u>I can just read it in their eyes that they know that</u>. Also, I can just get some feedback in the next lab section, so even though they have different materials, <u>the background is the same</u>. I know that they learn and they improve.	3 2	3 2	3	
8	13:29: COLLEEN: So now thinking back to the two labs that you TA'd in our studio with the cameras—so we had the smartphone lab and the traditional lab. Which of those did you prefer to TA? And I know it was a long time ago but which of those did you prefer to TA or which one did you think that students got more out of? TA: I think that smartphone… I don't know. COLLEEN: And that's ok. TA: So, sometimes the students need to compare their results. Actually, I don't even know if the other groups should use the same instruments. So, you know, some students they used the Apple system— COLLEEN: Which system? TA: The Apple system – the iPhone— COLLEEN: Oh, yeah, sure. Ok. TA: And other groups used the Android, and also the interface[s] are different. So they need to do some comparison with each other and that makes it difficult for them. [Editor's note: This lab was prior to the version of the instructions that included detailed procedures for both types of smartphones.] And also the smartphone sensitivity is not very clear for them, so they cannot just try to know how accurate this lab is, but this can be improved, actually. We can just find some technologies situation for them to do that. But some good aspects is… the smartphones is [sic] an instrument you can find everywhere in your life. That is close to life. That is what I think.				

	COLLEEN: Yeah. 16:02: TA: That is what I thought. I don't really think that there is some reason that one is absolutely better than the other is because in physics experiments there is always something you can't find in everyday life, so you need to just build some instrument only for some kind of purpose, that is not something that if you have the instrument you can do it for everything. But for college students, I think that is a good try. COLLEEN: So you're saying that the smartphone is a good try? TA: Yeah. 16:55: COLLEEN: That's interesting. I hadn't thought about it that way. Did you have any other reflections on the smartphone versus the traditional group? TA: Uhh, it's hard to say. I think when I did the smartphone groups, the smartphone experiments, those groups they have to just devote some time to getting used to the smartphone so that they know things, but I cannot tell whether the smartphone will just help them to know the physics better, but there is one thing. Since the smartphone kids will always make the experiment simpler so I think they will focus more, their energy into the physics. COLLEEN: With the smartphones? TA: Yeah, with the smartphones, because the apparatus is simpler. COLLEEN: The interface? TA: But the traditional way they have to figure out what do we use this for and how do we use it? They need to spend some time on that. COLLEEN: Sure. So you think—Is it fair to say that they spent more time learning one interface than the other? TA: No, I don't think so. It's just – maybe it's just history […]. It wouldn't be a problem if this was a general case in every lab. Everyone is saying that the next smartphone should be better.				

	19:22: COLLEEN: And that's just primarily because that's something that they have? TA: Hmmm.. Yeah.				
9	19:30: COLLEEN: Do you have any other comments about anything that we talked about? TA: Well, just that our physics education here is very, very much better than what we have in China. COLLEEN: Really? That's interesting. I'm surprised. TA: Yes, I was really surprised when I instruct[ed] the first lab about the tape. COLLEEN: Oh, yeah. TA: That's a really good experiment. COLLEEN: That's like, the 208 lab? With the static charges? TA: I never did something like that. That's really close to life. It brings in some insight. 20:23: COLLEEN: Did you have labs in China? TA: Oh, no. We have labs. We have labs. About lenses and voltmeters or something, but never something like, 'give you a magnet' or 'give you a tape' or something like that. I never did anything like that. COLLEEN: Wow. TA: That's really good, I think. COLLEEN: So I see now why there's so much value in connecting things to everyday life. That makes sense. That was so great! Thank you so much!				
Total Average					**2.86**

TA for Semester 2

Q	Transcript	Agreed	Bin	Colleen	Total
0	00:00: COLLEEN: Is it ok if I record this?				

	TA: Yes. 00:12: COLLEEN: Ok, so yeah I'm basically just going to ask a bunch of questions about how you TA in general. There will be one question about the labs that we did, and that's pretty much it! If you realize that there's something later on, you can just do it, and that's fine./ So you don't have to answer them in order or anything; that's fine.				
1	00:34: COLLEEN: So the first one is, how do you maximize student learning in the lab? TA: Um. I think, I mean, I guess I can only describe it by how I TA in general and uhh, maybe I can go to the specifics on that. I think that most things in life, right, through when we do them ourselves, so like, in lecture, they're being *told* how things work and whether it's in the lab, or now, this semester, I was a problem-session TA, umm, you know, I try to lead them. I try to give them a hint that they should look around this corner or that corner. Um, not literally. And obviously encourage them if they look around the right corner, and usually discourage them, usually non-verbally, actually for those things if they're looking around the right or wrong corner. I sort of go, "Mmmmm…" [in a skeptical tone] and I kind of give them crap based on their choice of path, and in particular, problem, and I feel like that maximizes it just because it gets them, by not being cold and dry, I think it sort of gets them really – how do I say this – I think by not trying to engage them on a sort of dry, intellectual level, it sort of makes them present.	3 3 3	3 3 3	3 3 3	**3.0**
2	02:06: COLLEEN: How would you describe your role, then, as a lab TA? TA: Um, well, I guess for me, I take it to be that I am not a lecturer. I had a student, maybe my first or second semester, and she was really sharp and she would always stay late packing up and stuff. Sometimes I would help her with her homework and stuff, so when she made this point to me that I'm about to say, it really stuck with me. She said—I feel like I've always been a person who lectures very little or who puts very little on the board and stuff, but even as little as I did, like three to five minutes, she said 'Yeah, you know. Nobody's really listening to you.' And she was like, 'It has nothing to do with you, but people aren't really paying attention. They	3	3	3	**3.0**

	just want to get on with the work.' And so I don't see myself as a lecturer. What was the original question again? COLLEEN: How would you describe your *role*— TA: My role? Yeah, my role is to be, you know, like a sight-hound, a dog, a guide. You know, I think they have all the tools either in their notebooks or in their brains already, and I just want to kind of be a cheerleader and just kind of encourage them that they can get through the problem in front of them. Some are, you know, in these problem sections, and that's something I'm going to talk about later today – or maybe not later today, but sometime soon – some of the problems are like insanely hard and so I had to be more than just an encourager, but I really don't like that. If I have to *teach* them a method, I think that we're really kind of off. COLLEEN: Yeah. TA: …from what the labs should be. But, that's not a […] 04:05: [Discussion of problem solving session questions specific to NCSU ensues.]				
3	05:08: COLLEEN: How do you know when your students 'get it', when they actually understand something? TA: I think that, um, deception is one of the hallmarks of intelligence. So actually I think that is a really hard question. COLLEEN: Yeah, you're right. These aren't easy questions. TA: No, I'm sorry. I'm searching through my memory to find like a genuine … actually, I think that the real, the *real* moment where I really believe it is when there's sort of a sense of wonder in their expression. If they're like all of the sudden, like they drift for a brief moment, that's an indicator to me that they've – they're either completely lost or they've kind of accepted that this thing is not common sense but they do understand it. I think that's really really hard because people, especially when they're first learning science, I think, their egos are in great danger, and I think a lot of kids don't want to admit if they are really struggling to get it. I have had a couple of students this semester, who, I knew that they weren't getting it. And I—It was painful because they weren't receptive to it. But after class I'd try to be like, 'guys, you gotta – like, I know what's going on, and you guys gotta	3	3	3	**3.0**

	ask more or read more after class or something.' Yeah, we can come back to that one.				
4	06:55: COLLEEN: Ok, that's fine. So, in the lab setting how do you decide what you're going to teach or not teach? Or what you're going to talk about in that first minute, if you do talk about anything at all? TA: I always keep it to the general. I don't – unless it's like a specific relationship that I feel like doesn't take an interesting insight to arrive at, like 'guys, you should know F = ma.' If it's like one of those things that, like… I try to only really give them – for example, we did an example where there's a cart that's traveling, and it's a Hot Wheels cart. And it's gotta go through a loop and then how far does it go off the ramp. And it was like, what's the radius of the loop, and what's the distance that it goes off the ramp, or whatever. And we started from a specific height, and basically what I said is 'You gotta consider conservation of energy.' I really only give them that, and that's it. And I think that's all I really talked to them about. I also tried to talk to them about the assumptions that they have to make if they're non-obvious. But I have really gotten to the point that it's rare for me to talk more than 60 seconds in the beginning. It's *really* rare.	1	1	2	**1.0**
5	08:18: COLLEEN: Ok. How do you decide – and this is kind of a hard question. This was not written specifically for our labs, so this might not be applicable—but how do you decide when you're going to move on to the next activity in the lab, or when you're going to push a group of students forward? TA: Well, so I'll preface what I want to say to that question with: my grading philosophy tends to be that in the first half, I'm tough, or I'm critical. COLLEEN: The first half of the semester? TA: Of the semester. I'm fairly critical of what they do—well, the whole semester I'm critical of the way that I talk to them, and I don't really – and I'm not too worried about their feelings when I'm facing them but I'm also a lotmore critical with them in the first half of the semester with their grading and I – what was the question? That actually was relevant, but I can't – 09:24: COLLEEN: How do you decide when you're going to push them forward?	1	1	1	**1.0**

	TA: Right, right, right. Yeah. So, but I still recognize that without any work done, I have to not give them credit. So really the only thing that pushes me through the labs or their assignment is needing them to have had an exposure to all of the material that we want to present to them in that assignment and that they at least, yeah, that they were at least exposed to it and that they show me they were exposed to it by writing in each section. I try not to interfere, and I find that by and large, they do want to push through it. So it's pretty rare, because our projects and assignments are typically – it's – I can't think of an example right now but I find it pretty rare that you guys have to finish this *chunk* and that then there's this other *chunk* that is substantially different so much that they might have forgotten that they needed to move to it. I find that to be pretty rare, so that question is hard from the sense that I'm not sure it is terribly relevant because our [assignments] are pretty stream-lined. 10:42: COLLEEN: Pretty linear in that the students do part a and then they do part b and so on? TA: Yeah.	1	1	1	
6	10:50: COLLEEN: Ok. Cool. How do your students—do you think—learn physics best? TA: This kind of reminds me – the first thing that came to mind was – in my classical mechanics class, my professor told me—I was like trying to work on a problem, a homework problem. I went to her and talked to her and there were a couple concepts in the homework problem that were so foreign to me that finally she said, 'Look. You may need to go find similar problems and their solutions.' I think that you learn best by repetition. I think one of the hardest things about – I think the central difficulty about physics in my mind is that our common sense experience which develops our intuition is not very good at solving these problems. So I think exposure to, you know, I don't think so far as learning by rote or memorization is what I mean, but just exposure to any problems that are variations on the same principle, and then being exposed to how people solve these things throughout history, *a lot*. I don't know. Maybe at the freshman level, they don't need the solutions as much, so maybe I'm answering more broadly…	2 2 3	2 2 3	2 2 3	**2.5**

	12:24: COLLEEN: Well, I mean, that's ok. TA: At their level, yeah, I mean, I think <u>connecting equations with the experiments in the labs</u> – I mean, I think that if they're really paying attention then I think those two hours are really pretty good. I think the problem sessions are more … I mean, it was set up to help them prepare for exams, and I kind of think that that's not really what it is. I'm not sure that it terribly helps them really learn what physics is all about. <u>I think that the labs are *probably*—they *could* be—I don't know if it is or not, but they *could* be the best way, rather than the lecture</u>. You know, I'm actually reminded – I had a lot of friction with [another grad student] but he never came to lecture, but he ended up having a grasp of and doing better on a lot of the material in our first semester at least, than I think a lot of the other people in our classes. So I think that, you know, the lecture format is – I keep answering these questions by saying 'that's *not* how you—', but I just mean – I just think that … 13:40: COLLEEN: That there's something that you're getting from outside the lecture? TA: I think it's two things. I think that the connecting – the seeing the physicality of the labs and connecting it to the general principles like conservation of energy or the conservation of momentum, but then I think that having to go and do homework and having to use equations, and manipulate equations, which are very abstract—I was talking to somebody else and I was actually responding to somebody the other day talking about, well the other day—I know I'm rambling now, but one of the most frustrating things to me in Quantum was that I very much wanted a one-to-one correspondence of various steps through the solving process with physical reality, and that doesn't exist. And I had a hell of a time because of that. And so I think that, yeah, so yeah just like long, long, long exposure to manipulating equations is the other side of it, but just to reiterate—that *that's* half, and then the other half is the physicality of the concepts in the lab.	3		3	
7	14:43: COLLEEN: Ok, great. How do you know when learning is occurring in the lab? TA: I think when – I think when kids have that kind of far				**1.0**

	outlook – I can't remember what I said earlier, but, yeah, I mean, when – I think that it's pretty easy for me to tell <u>when people are sort of absorbed in themsel[ves] than what's in front of them, and if they're not absorbed in themsel[ves],</u> then I think it's the case that they *have* to be learning. I think it's just the case that they *have* to be learning.	1	1	3	
8	15:28: COLLEEN: Ok. So this next question is sort of more specific to the two courses, or the two sections that you did last semester in the lab room. So thinking about kind of that smartphone group versus that control group was there a group that you preferred to teach, or was there a group that you thought the students were learning better from? Which one do you think kind of 'worked better' overall? TA: I'll be frank. I think it's been too long to really accurately answer that. I don't remember any substantial difference. I think that this seems more like a secondary judgment but it does seem to me – this doesn't seem relevant, but whatever tools you can get in somebody's hands, I think that's fine. I don't remember there being a substantial difference. I mean, yeah. And beyond that, I think it's just been too long. 16:32: COLLEEN: Yeah, and that's fine. That's completely understandable. TA: Yeah, I mean, I can't *critically* –				
9	16:36: COLLEEN: I totally understand. And so the last one is, just do you have any other final comments about anything either those labs or about your TA experience in general? I realize it's an open-ended question, so sorry about that! TA: Yeah. What is this questionnaire going to be used for? COLLEEN: I probably should have told you that. It's just going to be part of my study and I'm just trying to get a feel for—you know, I ran these labs three semester with three different TAs, and I'm definitely using all of the videos from the semester you TA'd and I'm trying to determine which of the other two semesters I should use. Because I'm probably going to use one and not the other so much, and so I'm trying to get a feel for how your role in the lab compares to the other TAs' roles in the lab. So this is kind of – this is like a standard – I don't want to say				

	'measurement' but it's a standard survey that's used to figure that out. TA: I'll tell you – I think that the mistake that's being made at NCSU with labs and with actually with the problem-sessions I think this might be easier to solve. I think, actually, later today I'm going to reach out to [the professor coordinating the problem-solving sessions this semester]. He's not running them again, I think, but somebody is. I think that they [the problem-solving sessions] are pretty close. They've got the baseline materials, as far as the problems for each week. There are a couple of grammatical errors, there's a couple of problems that are too hard or at least they're too hard in the most obvious way to solve them. Maybe there's some clever trick and we missed it. The labs seem like somebody – seemed like whoever wrote them was not—did not then look to gather feedback and criticism such that they could really sharpen the labs up. And that. 18:53: COLLEEN: Oh, the labs? Not the problem-solving sessions? TA: The labs. So specifically, the labs. And the reason that I say—I'm a person who I very much believe that despite what the military does in action, I believe that the way that they structure themselves is actually quite effective. I think that one person at some point, the buck has to stop. And I think that what I would say about labs is that, crap—I lost – I mean I *had* the thread, but I lost it. I mean, specifically, I want to say and I'm not even really trying to be diplomatic, but I just – I feel that the concepts are right. I feel like the materials are all there, but I think that – I really missed exactly how I wanted to say it. I had it in my head. What was the question again? 19:56: COLLEEN: It was just asking for general comments about kind of the labs. TA: Yeah, I think that it's almost like no one is expecting to personally take heat for the little, both the little detail inconsistencies as well as the feeling by students that the labs maybe don't like up exactly with the lectures, that – like, there's nothing – I mean, the reason that I'm having a hard time making this criticism is because there's nothing – and it's definitely a criticism – is that there's no *one big thing* that stands out to me, like 'oh man, we just messed				

	this up.' It's more like, the NCSU labs—physics labs, physics 1 and 2 labs are the only exposure that most of the world is going to have to NCSU Physics. And I really am struck that we aren't taking it as a department as the big opportunity to impress the laymen and I'm really just struck that nobody is like – and not at a grad student level—but at an *administrative level* has taken it and been like, 'let's make our department shiny to the rest of the world.' There's something just a little – lacking a little polish. And that's really hard, because somebody listening to this could very easily dismiss what I'm saying, saying 'Well, how am I supposed to work with that? What am I supposed to fix?' Well, go teach a lab for a semester and then it will stand out. Do you know what I mean? COLLEEN: Yeah. TA: Hey, I for sure. And you and I have talked about this. I, for *sure,* could have been way more diligent about – I mean, really – that's what somebody is going to have to do—is go through a semester and be like, 'Oh, *this* is why things feel funny.' But other than that, I think that they're supremely important for their learning, and I guess there will always be criticism. COLLEEN: Alright, great!				
Total Average					**2.07**

TA for Semester 3

Q	Transcript	Agreed	Bin	Colleen	Total
0	0:00:00 COLLEEN: So is it ok if I record it? And then… TA: Yeah. COLLEEN: Ok. Perfect. Ummm… So there's nine questions total that I'll ask you just about your TA experience in general and it's not like I'm judging you in any way, just do whatever you want to say about it, is great and then, um, and if you realize in answering a question later on that				

	you want to go back and answer something, that's fine. Ok, cool!				
1	00:34: COLLEEN: So first question: How do you maximize student learning in the lab? TA: Maximize student … I feel like you have to get them interested. Interested in what's going on because otherwise they just, they might retain it a little bit, but then might retain it a little bit but then it just disappears. Whereas if you get them interested they would uhhh they'll remember it. Like there were a couple of times that I think I showed them the derivative definition of force and I think later on in the semester, at least [one student in the MyTech section] remembered it. And he was very interested. I talked to him about physics somewhat. So that's what I would say. COLLEEN: So just trying to appeal to something that they've already…? TA: To make them actually care about what it is or else they're just not gonna learn it. They're not gonna remember it. They're just gonna forget it. That's why people remember all the Pokemon. It's because they liked Pokemon and they still remember a lot of their names, but they can't remember simple definitions of physics. It's not as appealing.	3	1	3	**3.0**
2	01:47: COLLEEN: How do you describe your role as a lab instructor? TA: I don't know. I looked at it more as I was helping them get through the experiment, like, guide through. Like usually everything's written up already and I'm there to help them understand the physics that's going on. And help them think about it. I tried to ask questions from them to see if they could figure things out, because that's what they always tell us to do in all the different things. All the literature says it's uhh…what's that Greek philosopher? COLLEEN: The Socratic— TA: Yeah, the Socratic method.	3 5	2 3	3 5	**4.0**

3	02:40: COLLEEN: Awesome. Alright. So how do you know when your students understand? TA: Ummm…I definitely know they understand when they answer the que—like, when you're going through that Socratic method and they get the correct answer. Um. I think, that is hard to know, too, cuz you're not sure if they know just that particular instance. That's why I like the labs because I like to *show* people what's going on, and then that at least reassures me that they'll understand. I feel at least *seeing* something they can remember *that* when they're on the test, maybe. But I'm not sure if they're gonna remember. COLLEEN: So more, just like, seeing it kind of … in the physical world… as opposed to a sketch of it in a textbook, kind of? Like, that sort of thing? TA: Yeah. I think I *know* that they've learned something when they produce this new information, like when you're asking them questions and then it's like 'Oh, *this* is the answer.' Yeah! Yes, you have it. And they, sometimes, you know, you'll get them to explain it and that's a good way to know that they know what's going on. Um. So I guess the only way you can really know is by asking them, is by asking them. Kind of "quizzing" them and asking them to show you their knowledge. It's like a little test or something. They have to demonstrate something, of course.	2 2 2	2 2 2	2 1 2	**2.0**
4	04:18: COLLEEN: In the lab setting, how do you decide what you're going to teach and what you aren't going to teach? TA: Ummm, like up on the board? COLLEEN: Yeah. TA: Usually, by Fridays [when the MyTech and control groups are run] it's usually whatever we were having the most problems with in the old, the other lab sections. Um, you know, and then it probably kind of changed over the semester, because at first I wasn't really sure what to do	1	1	3	**1.8**

	with the board and then I started writing equations up there, useful equations and equations… By the end of the semester, I would write the equations that I knew I would have to explain up there. And then they would have, you know, they would come in and they would see some equations and they wouldn't even know what's going on. And then I could at least have them up there as a reference, and walk them through it. That was always useful stuff to teach. And then every once in a while, I would try to relate, to relate it to something else. I think on the last day I was talking about Maxwell's equations and someone, just because he was talking – <u>he was really interested in</u>, um, like Stoke's equations, and I was like 'Oh, well, you know, it's all vector fields and stuff,' and I was like 'these are really similar' and he was like 'Wow! This is really cool!' So sometimes I would try to teach little things like that to try to keep people, ya know, cuz <u>that's how I got really interested in physics</u>. I heard enough cool things and I was like 'Ya know, I gotta learn this!' and so I guess I would try to, I don't know, in the moment, I might try to teach something kind of cool. Like, usually it was the stuff that was more difficult or the stuff that my other classes had problems with. 05:58: COLLEEN: So what about on your first class, like your Monday class. Was it --? Did you --? TA: I would usually –especially in the beginning of the year—<u>I would pull up the book, the book, like the lab manual</u>, and I would put it up on the overhead and that would have some of the key equations that *I* thought would be important. Sometimes that would change, but I would at least put the stuff that I thought would be useful to have up there.	3 2 1	2 1	3 1	
5	06:33: COLLEEN: Alright, cool. Ummm. So how do you decide when to move on to a new activity				**1.0**

	in your lab? TA: To a new activity? COLLEEN: And this might be kind of a hard question for our labs. TA: So, uhh… yeah. What is that --? COLLEEN: So, you know, if they're all doing one thing, and for some reason you need to push them forward, is there--? TA: Like how to get them to not be stuck on a question? COLLEEN: Yeah… TA: Usually, I mean, with our lab that would become an issue sometimes. People would get stuck. If people were having an especially hard time with people and they got stuck on it, umm… I had a lot of that happen in my Monday labs. In my Monday labs, I would actually *sit down* with my group. They have these little portable white boards. So I would get the little white board and then say, 'ok, we got it. Let's just get through *this.*' Like, I guess, focus a lot of attention on a group that's stuck. And, of course, if WebAssign is having problems, it's like 'Ok, let's just pass this.' Ummm… Yeah. COLLEEN: But otherwise, you're sitting down with them? TA: Yeah. But sometimes, you know, sometimes they'd run over a little bit. I had to have a couple of other people in my other classes do the Python… I think in one of my other classes I showed them my Python because they just ran completely out of time, but that was – there was some problem, or there was some equipment that was broken. So I at least, for them, even though I couldn't get them to move on during the class because we were just fussing with equipment, I at least tried to *show* them the stuff. After, and we went past class. 'You guys need to *see* this at the very least.' So.	1	1	2 1	
6	08:32: COLLEEN: Alright good. How do you think the students in the class learn physics				**2.0**

	best? TA: It <u>depends on the student</u>. Um, see, I'm biased. *I* at least learn it best by seeing it. And I think some of them learn it best by seeing it. Like there was one time in the lab where we were talking about air resistance, and they were saying that the net acceleration on the falling tissue paper was gravity, and I was like 'no,' and they didn't believe. And I was like, 'If that's true, these two objects will fall at the same rate.' So then I knew that they knew it when, what's his name, [student in control group] shoved—he had shoved the paper down. And I was like, 'Look! You had to apply a force to match g!' and <u>so then I knew that they understood it then</u>, which was really nice. And so, at least, for them, they learned very effectively by *that* demonstration. I think sometimes people need just examples, instead of derivations. They get a lot of derivations in class. I mean, in physics, you *have* to give a lot of derivations in class, but there's not as many examples. I think *that* messes with people. Especially in the tutorial center, they happened upon a problem they didn't see in lecture. They had *no* idea what was going on. And so, I think, but then, if you show them an example—<u>it was funny because I would only have to help them on a couple of problems</u>. Like, the first two on their homework, maybe. And they'd usually go through the rest of it ok, cuz they'd get those initial easier examples because then at least they could understand. COLLEEN: Extrapolate? TA: Yeah. I guess some people, the physical demonstration, some people they just need the theoretical examples.	1 3 2	1 2	2 3 2	
7	10:39: COLLEEN: Ok, cool. How do you know when learning is occurring in your laboratory? TA: [silence] COLLEEN: I know; I didn't say these questions were easy!				**5.0**

	TA: …when learning is occurring… COLLEEN: Like, are there certain— TA: I think that the best way to know that learning is occurring is <u>when they start playing</u> with whatever it is. I remember, my Monday lab was bigger, so there was just more chances for this to happen. But especially when a group would get to a certain point in the lab, and then they would waste time, but they would waste time, by… Ya know, there was that one with the marbles rolling down the ramp? COLLEEN: Yeah. TA: They just decided to start seeing, like, if they gave it initial pushes, like, how much that would add. And that's them *understanding*. And they would use their kinematic formula. They'd be like, 'there's a v_0 right here!' and I was like, 'Wow! That's—that's intense! Like, that's actual people wanting to learn!' COLLEEN: Like going a step beyond! TA: Yeah. So, when they're taking an initiative to learn, you know that learning is going on. I think that's the best way to at least, understand they're learning. Sometimes it's just <u>when you're going through the Socratic method, and they answer the question the right way,</u> or you know. Sometimes when they bring up an interesting point, it's – maybe if it's not even necessarily *correct*, but you know that they're going through the steps. You have to get things wrong to learn.	5 5	5 5	3 3	
8	12:37: COLLEEN: So this one is more about the labs that you dealt with with me. Which of the two sections, either the smartphone section or the control section, did you prefer to teach? Or which of the two sections do you think that students got more out of? TA: I think that the smartphone one probably. COLLEEN: Really? TA: Yeah, and that's because with the other section, we always had weird equipment problems. Cuz we'd have to bring it over from				

	the other lab. I mean, that wasn't—so we did have quite a few successful labs, but I did like the smartphone. I feel like some people – there was the one time where you were dropping the phone onto the pillow and the net acceleration from the phone's perspective is zero, and that's how they would do it. And every – I'm pretty sure *every* single group answered that first question wrong. They said that the net acceleration was g. And so, I remember just telling them—they'd be like 'I don't believe you! We think it's 9.8!' And I was like, 'Ok! You're going to drop your phone! And it has this sensor, and it's like – look we shake it and reads it, so you know that's what's happening!' and we dropped it and it's zero, and that's how they get the *value* of g. I think that was like really good, let's see… What was another lab? That was the first one that sprang to mind. COLLEEN: We did … umm… So we did the very first one was the one where they were just playing around with the phones… TA: Oh, all the cart ones. COLLEEN: Oh, yeah, all the cart ones. TA: The carts! There was, uh, yeah, we had to draw the – a lot of times when there were the questions about drawing the shape of the curve, they *always* draw that wrong. And then they'd be like 'We don't believe whatever you say it's gonna be.' But then they would—it's not only that they would believe what the graph did, but especially because, uh, I dunno. They'd pull it up and then they'd *see* it. They'd *see* that graph, and it would make *sense* at that point, and they'd be like, 'Look! See! This is where it hits it and it turns around.' 14:59: COLLEEN: So what do you think was causing their issues with, like, *prediction*, you know, of the graphs? TA: Well, so like in our TA class recently, our final project was a 'discrepant event' where we				

	had to, uh, present an event that contradicts common sense. 15:20: COLLEEN: What's it called? TA: A 'discrepant event' is what they called it. And so, um, there's a lot of – in physics labs, there are a lot of discrepant events, where they think it's going to be one way and instead it's a completely different way. So I think that people have an idea-- just every day people have an idea of what physics is like and so when they, they're answering these questions they sort of project that, you know. And, uh, yeah. They – it's basically the sort of common sense way to think about it, but it's not necessarily right, and so… Because a lot of them, they would say similar things. Like everyone on the pillow day, it's probably – it's acceleration is -9.8. It's because they're thinking it *is* accelerating, like… COLLEEN: Like in fixed space, where you have fixed coordinates. TA: Mmhmm. Yeah. And so the concept there is that the sensor is *on* the phone, and umm, that's something that they learn. COLLEEN: Ok. The last question is… any final comments on anything? TA: Uhh… I don't know. 17:20: COLLEEN: Or if there's anyway – do you think that like there's a way to improve the labs? Like, should we use the smartphones some of the time? Or…? TA: I *liked* using the smartphones. It was disappointing when we'd have labs that didn't use the smartphone, I felt. I think it's a good idea that you guys are building your own app that, at the very least, will have everything that *we* want to have in it. That would be nice. Like, maybe, one thing it would be nice if you could manipulate your graphs on your phone. Not have to put them into Excel, and then just save a graph on there, and then just look at it. That would – and then just export the picture of the				

	graph. COLLEEN: Ok, great. That's actually something that we're working on. TA: OK, fantastic. COLLEEN: We're working on like a pause ability, and then like a zoom, and then a rewind sort of thing. TA: Oh, wow. COLLEEN: So yeah, that's all in the works. But yeah, that's a good suggestion! TA: Yeah. COLLEEN: Thank you so much!				
9					
Total Average					**2.69**

Appendix C: MyTech Lab Manual

Lab 1, Procedure

Objective

The purpose of this laboratory exercise is to determine the axes of your smartphone and use your knowledge of those axes to discover what the gyroscope measures.

You will then be asked to think about the relationship among acceleration, velocity and distance for a cart bouncing off of a spring.

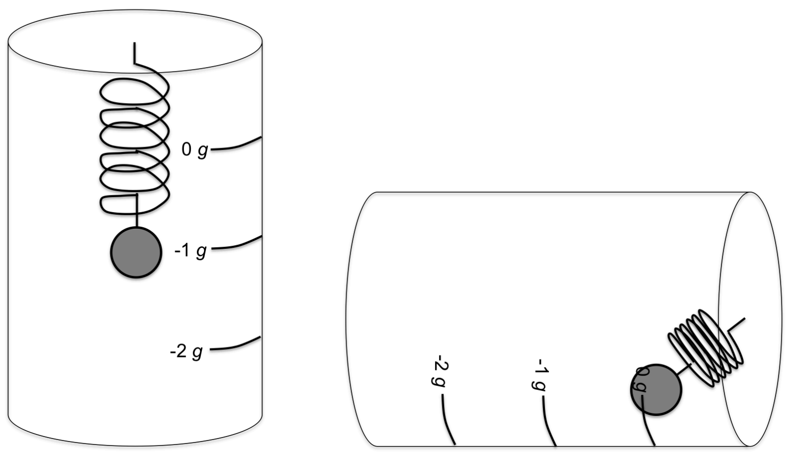
Discovering the Smartphone's Axes

Background

Use real-time accelerometer graphs ($a(t)$) to determine the $\pm x, \pm y, \pm z$ axes of the device.

Procedure

Consider a spring scale with a mass attached to it, as show in the diagrams below.



If the spring scale is held vertically, the scale shows that the bob experiences an acceleration of

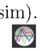
$$a = \_\_\_\_\_\_\_\_ g = \_\_\_\_\_\_\_\_ \text{m/s}^2.$$

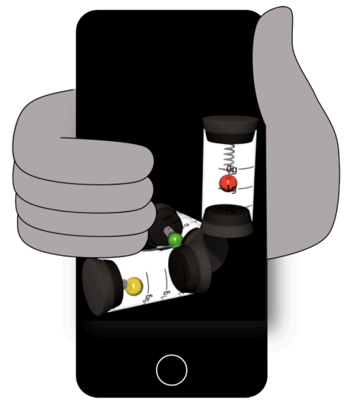
If the spring scale is held horizontally, the scale shows that the bob experiences an acceleration of

$$a = \_\_\_\_\_\_\_\_ g = \_\_\_\_\_\_\_\_ \text{m/s}^2.$$

Your smartphone contains three miniature versions of these spring scales (one for each axis) inside of it. Your phone contains this combination of sensors (called the "accelerometer") so that it can figure out how you're holding the phone.

iPhone users: Download and open the SensorLog app (by Berndt Thomas). Make sure that the accelerometer mode is enabled by tapping the "ACC" button in the upper left.

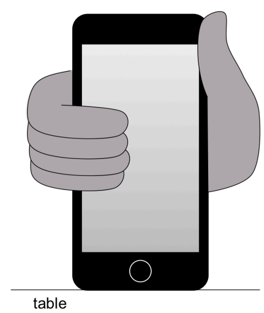
Android users: Download and open the AndroSensor app (by Fiv Asim). Tap the accelerometer graph button  so that the app graphs the accelerometer readings.



Smartphone accelerometers act like a set of three spring scales, one on each axis, to determine the orientation of the phone.

Move the device around and observe the three colored lines on the plot. Each line represents the acceleration experienced by the device along a certain axis. The instantaneous value is also displayed at the bottom of the plot. Note that red corresponds to the x-axis, green corresponds to the y-axis and blue to the z-axis.

Begin by orienting the smartphone upwards so that the bottom edge of the smartphone is making contact with the lab table. Keep the phone stationary and observe the accelerometer values.



✎ To the nearest multiple of g, record the accelerometer values along each axis:

$$a_x = \underline{\hspace{2cm}}\, g, \qquad a_y = \underline{\hspace{2cm}}\, g, \qquad a_z = \underline{\hspace{2cm}}\, g$$

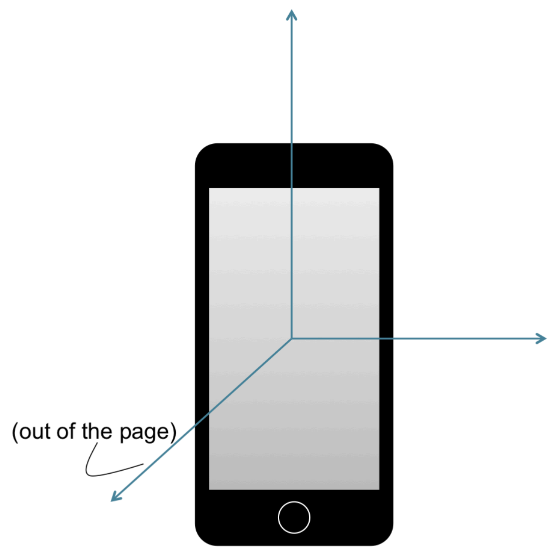
✎ From this, guess the orientation of one of the axes.

Flip the phone upside-down so that now the top edge of the smartphone is making contact with the lab table.

✎ What happens to the values of a_x, a_y and a_z?

Repeat the experiment for other edges of the smartphone so that you can determine the other two axes.

✎ Label them in the diagram below.



Now we will use our knowledge of the axes to discover what the gyroscope measures. Enable the gyroscope setting on the SensorLog app.

✎ What type of motion do you typically associate with gyroscopes? (e.g. linear, rotational, circular, parabolic, hyperbolic, etc.)

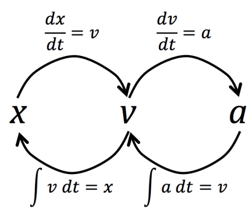
Try to verify this notion by moving the smartphone on the surface of the lab desk and observing the resulting gyroscope graphs.

✎ Was your guess correct? If not, try other types of motion until you have determined what type of motion the gyroscope measures.

The Relationship Between Acceleration, Velocity and Distance

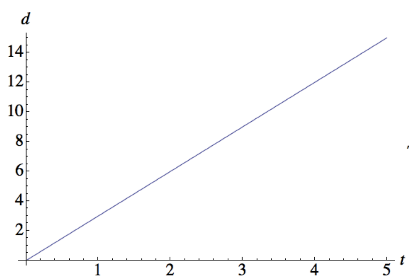
Background

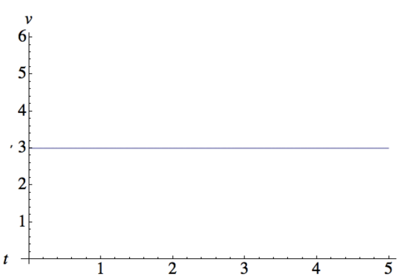
Recall that you can use derivatives (which correspond graphically to slopes) and integrals (which correspond graphically to area under the curve) to switch between position, velocity and acceleration.



Thus, since the derivative of position is velocity, the value of velocity at any given time corresponds to the *slope* at that time on the position versus time graph. So if your position versus time graph had a constant positive slope, this would correspond to a constant value of velocity.

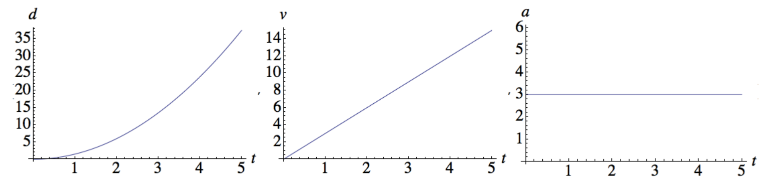
If, for example, distance is given by $d(t) = 3t$, the resulting distance versus time and velocity versus time graphs are as follows.





✎ What will the corresponding acceleration graph look like?

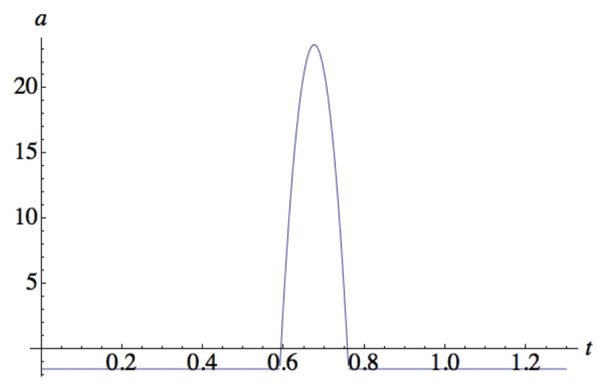
Now, suppose the graph of distance is a bit more complicated so that the object is constantly *accelerating*. Then, the graphs would look like:



Procedure

Watch the video at the following link: `http://go.ncsu.edu/bouncingcart`

Here is the corresponding acceleration versus time graph for the first cycle (toward the spring, bouncing off the spring and then returning to the starting position).

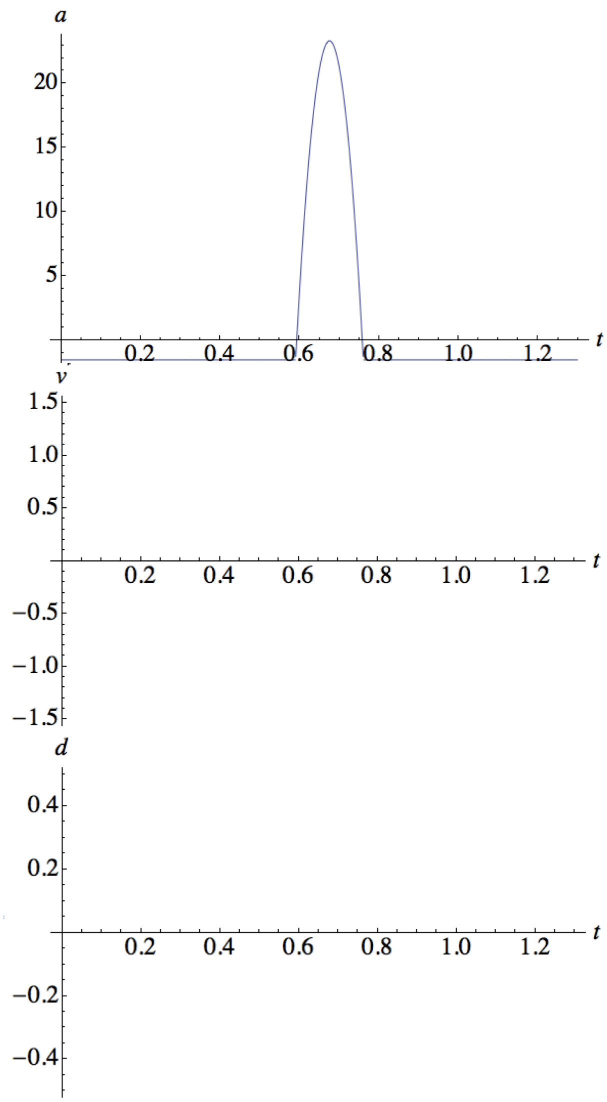


Now, "work backwards" and determine the corresponding velocity versus time and distance versus time graphs.

☞ *Think about this slowly and carefully, and ask questions if you have them. We will use this technique frequently throughout this course.*

✎ Once you and your group members agree, sketch your graphs in the space provided on the next page. Be sure to label your vertical axes numerically.

📷 After you have completed the sketch, **take a picture of it with your smartphone** and upload it to WebAssign. (You may need to reduce the size of it using a program like Paint before uploading it.)


a
20
15
10
5
t
0.2
0.4
0.6
0.8
1.0
1.2
v
1.5
1.0
0.5
−0.5
−1.0
−1.5
d
0.4
0.2
−0.2
−0.4

Return to a, v and d

Background

Let's check our velocity and distance graphs for the bouncing carts with reality. To do this, we will use Tracker, a video analysis software.

Procedure

Open Tracker. Open the File menu, then click "Open File...". Navigate to Documents > Tracker > resources > experiments > bouncing_cart.trk.

In the lower-left (just below the video), press the play button ▶ and pause it *just as the cart reaches the top of the path for the first time* (at approximately frame 45) with the pause button.

Look at the graph on the right side of the screen. Click the label "x" for the vertical axis. You will see a menu that allows you to plot many different physical quantities. Choose a_x, the horizontal component of acceleration. Compare the a versus t graph in Tracker to the one at the top of the previous page. They should be close to identical.

✎ Now, change the graph so that it displays v_x versus t. Compare the actual velocity versus time graph in Tracker to the one that you predicted and uploaded to WebAssign. If they are different in any way, explain why the Tracker results appear the way they do.

✎ Now, change the graph back to its original state so that it displays x versus t. Compare the actual position versus time graph in Tracker to the one that you predicted and uploaded to WebAssign. If they are different in any way, explain why the Tracker results appear the way they do.

Lab 1, WebAssign

MT Lab 1 S14 Lab Intro and Measurement (5292917)

Current Score: 0/100 **Due:** Sun Aug 31 2014 11:59 PM EDT

Question	1	2	3	4	5	Total
Points	0/2	0/30	0/20	0/20	0/28	0/100

Description

This is a group assignment.
Be sure that you read *all* of the instructions (under the "Experiment" heading below) before attempting any of the questions.

Instructions

Experiment

Instructions for the lab experiment.

Simulation

You should have already completed the procedure set out in these Instructions for an introduction to 3D computer modeling. You may find it useful to reference this document for one of the activities below.

The instructions for this activity reference three videos to watch. These videos are viewable from the VPython Videos YouTube Channel.

Read this description of group roles for VPython programming.

---

1. 0/2 points Group Roles [2434126]

Group Roles

Before you start the lab, identify who on your team will assume roles shown below. If necessary, read the descriptions of Groups Roles for Labs.

Lab Manager

Key: student name

Recorder

Key: student name

Skeptic

Key: student name

2. 0/30 points Lab 1 Discovering the Smartphone's Axes InLab [2679567]

What type of phone are you using? ---Select---

If the spring scale described in your instructions is held vertically, the scale shows that the bob experiences what acceleration?

a = ☐ -1 g= ☐ -9.81 m/s^2

If the spring scale is held horizontally, what acceleration does the bob experience?

a = ☐ 0 g= ☐ 0 m/s^2

With the phone oriented top edge up, record the accelerometer values along each axis to the nearest multiple of g.

$a_x =$ ☐ 0 g

$a_y =$ ☐ 1 g

$a_z =$ ☐ 0 g

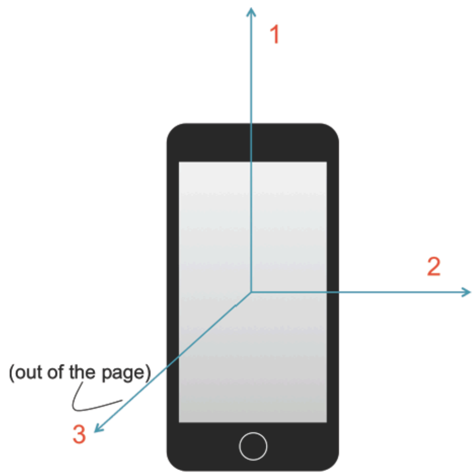
Flip the phone upside-down. What happens to the values of a_x, a_y and a_z?

$a_x =$ ☐ 0 g

$a_y =$ ☐ -1 g

$a_z =$ ☐ 0 g

Label the axes.



1. ☐ y -or- +y -or- Y -or- +Y -or- -y -or- -Y
2. ☐ x -or- +x -or- X -or- +X -or- -x -or- -X
3. ☐ z -or- +z -or- Z -or- +Z -or- -z -or- -Z

What type of motion did you find that the gyroscope measures? ---Select--- rotational

3. 0/20 points Lab 1 The Relationship Among a, v and x [2689334]

Suppose $d(t) = 3t$. Sketch out the corresponding *a* versus *t* graph. Take a picture of it, email it to yourself in *medium size* and upload it to WebAssign.

Important Note: WebAssign will immediately reward you full credit for any file you upload. Your TA will then review the files and award the appropriate number of points. Choose File No file chosen

Key: Picture of a vs t (horizontal line starting at (0,0) and running along the t-axis).

Sketch your graphs in the space provided on page 6 of your worksheets. Take a picture of it, email it to yourself in *medium size* and upload it to WebAssign.

Choose File No file chosen

Key: Picture of v vs t and x vs t.

4. 0/20 points Lab 1 Return to a, v, d [2689340]

Compare the actual velocity versus time graph in Tracker to the one that your predicted and uploaded to WebAssign. if they are different in any way, explain why the Tracker results appear the way they do.

Key: Compare v vs t.

Compare the actual position versus time graph in Tracker to the one that you predicted and uploaded to WebAssign. If they are different in any way, explain why the Tracker results appear the way they do.

Key: Compare x vs t.

5. 0/28 points Lab 1 VPython Upload [2689346]

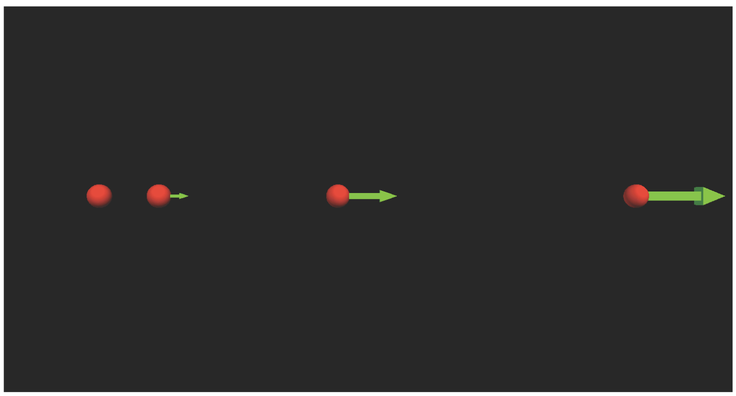
In the lab, you will be using VPython to simulate the physics principles you learn in class and compare them to the real-world experiments you will be performing.

The following exercises are practice with the commands you learned in your VPython homework assignment. For reference, the videos you watched can be found at www.youtube.com/VPythonVideos and the instructions from that homework assignment are available here.

1. Write a VPython program whose output looks like the image below. You can find a shortcut to VPython IDLE on the desktop.

IMPORTANT: Make sure that these are the first two lines of the program:
from __future__ import division (note that there are 2 underscores on each side of future)
from visual import *

Make sure the filename includes the standard ".py" extension. You may need to type ".py" as you name the file.



Upload your finished program: Choose File No file chosen

2. Copy the text in this file and paste it into a new VPython IDLE window: Program for problem 2

This program is intended to display the sun and the Earth (though not to scale) with an arrow pointing from the sun to the Earth, using references to variable names. However, there are several problems with the code that cause error messages.

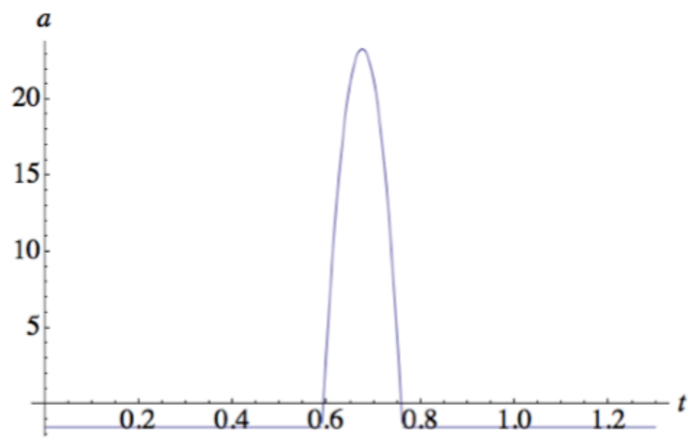
Attempt to run the program and read the resulting error messages. Try to fix the code so that the program successfully runs, displaying an arrow pointing from the sun to the Earth.

Upload your working program: Choose File No file chosen

Assignment Details

Lab 1, Student Responses to MyTech Questions

Here is the corresponding acceleration versus time graph for the first cycle (toward the spring, bouncing off the spring and then returning to the starting position).

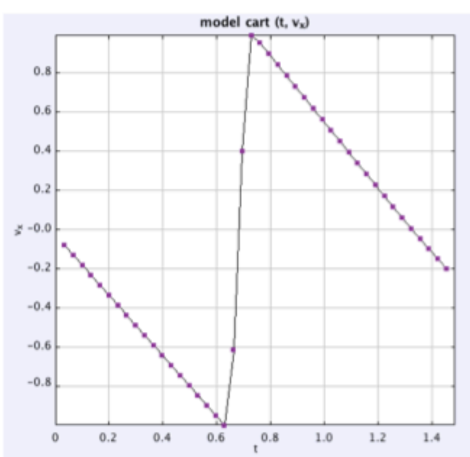


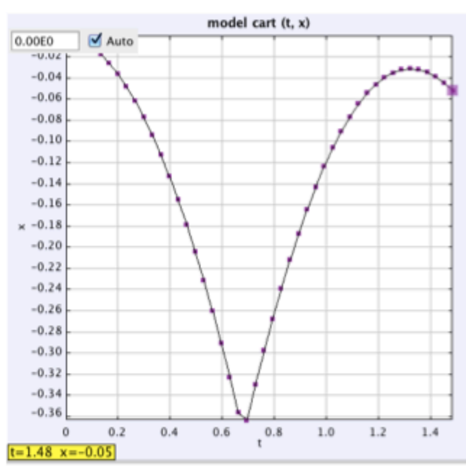
Now, "work backwards" and determine the corresponding velocity versus time and distance versus time graphs.

☞ *Think about this slowly and carefully, and ask questions if you have them. We will use this technique frequently throughout this course.*

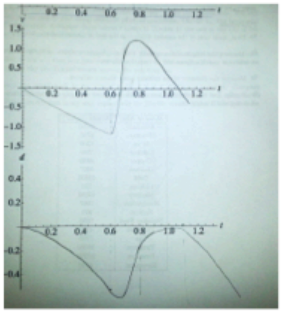
✎ Once you and your group members agree, sketch your graphs in the space provided on the next page. Be sure to label your vertical axes numerically.

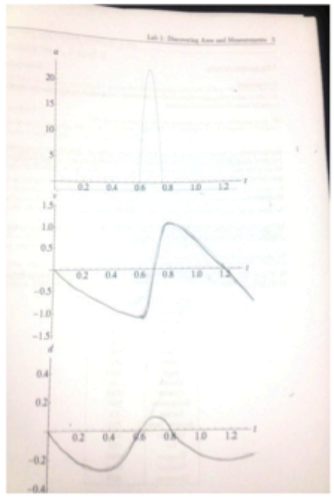
Key

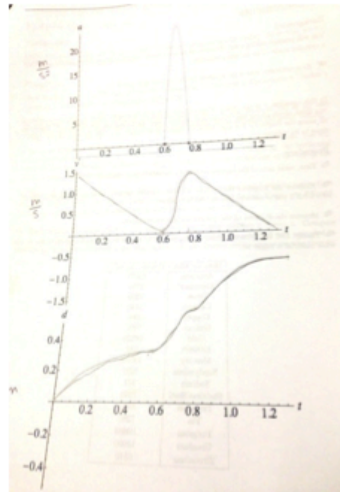


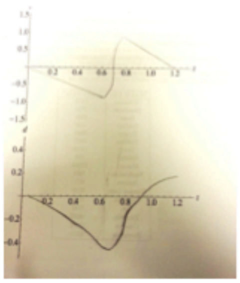


Fall 2013 Responses

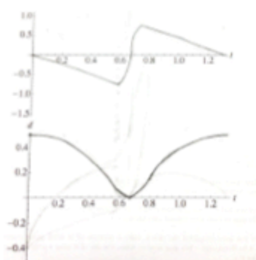


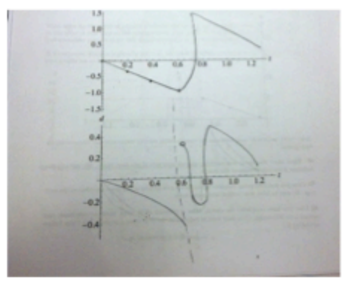


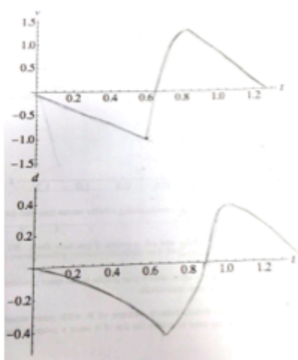


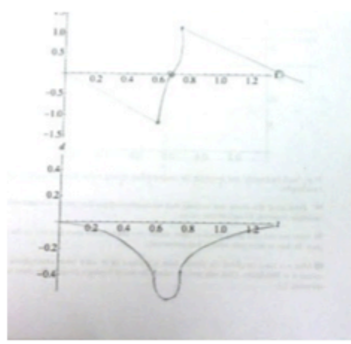


Spring 2014 Responses

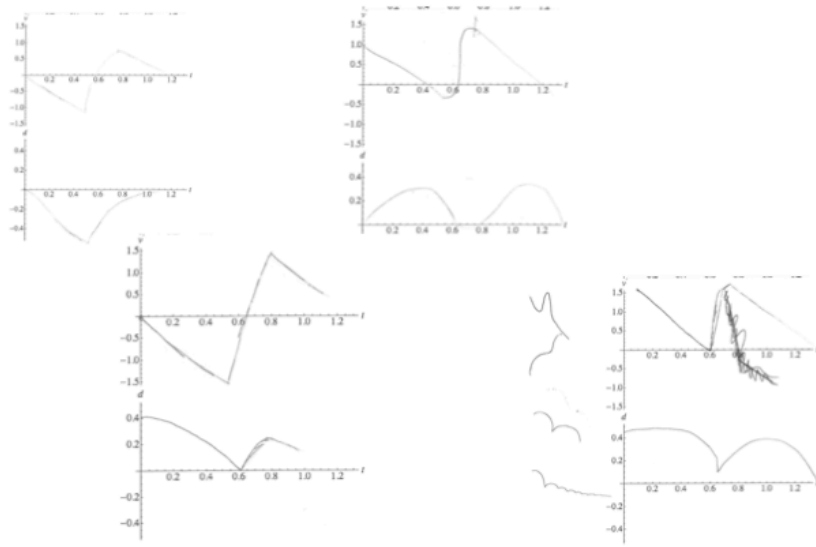








Fall 2014 Responses



Lab 2, Procedure

Objective

The purpose of this laboratory is to exercise your knowledge of the relationship among acceleration, velocity and distance.
You will then subject your device to a cushioned free fall and use its accelerometer data to determine an experimental value for g.

Free Fall

Procedure

1. ✎ Sketch what you think the acceleration versus time graph will look like when the smartphone is in free fall in the space provided.
   ☞ *Be sure to label the time period that the phone is in the air. Your sketch need not have a scale for time.*

   📷 Take a picture of your sketch and upload it to WebAssign.

2. Start by dropping the phone from a height of 1.0 m. (Should you measure from the top, bottom, or middle of the object?)
   ☞ *Do not let the drop height exceed 1.0 m.*

3. You will now record accelerometer data while the device is in free fall.

☞ *You will need to record accelerometer data often on your smartphone in this lab, so you should familiarize yourself with this process now and ask your TA if you need help.*
☞ *You may want to practice this process a few times before recording your data.*

iPhone	Android
Open the SensorLog app. Enter accelerometer mode by tapping the "ACC" button in the upper-left. Ensure that your accelerometer has the correct settings. (a) Tap the settings button ⚙. (b) Set the recording rate to 20 Hz. (c) Make sure that the only two sensors that record data are the accelerometer and gyroscope by "turning off" CL, MAG, CM, IP, OR and STATE. (These are all other sensors that we will not need in this class.)	Open the AndroSensor app. Press the menu button on your phone and tap "settings". (a) Click "graph height" and choose "large". (b) Click "update interval" and choose "very fast". (c) Click "active sensors" and select only "accelerometer" and "gyroscope". (d) IMPORTANT: Click "recording interval" and choose 0.05 seconds. (e) Press the back button to return to the AndroSensor main screen.
Press the play button ▶ to begin recording.	In the upper right, tap the encircled down arrow (or swipe from left to right on the screen) to reveal the "hidden" menu. Press the record button ● to begin recording.
Press the pause button ⏸ to stop.	Press the stop button ■ to stop.

4. Email the recorded accelerometer data to yourself and graph it in Microsoft Excel.
☞ *You will need to email smartphone data often to your lab computer, so you should familiarize yourself with this process now and ask your TA if you need help.*

iPhone	Android
Touch the browse button on the main screen. It should give you a list of all of your recorded accelerometer data, with the most recently taken data at the bottom of the list.	After you've finished recording, press the home button on your phone. Open "My Files". Browse to the folder My Files → All files → AndroSensor. *NOTE:* These next few steps may differ slightly, depending on what model of phone you have. Ask your TA for help if you need it!
Touch the file that contains the data that you want to analyze.	Check the box to the left of the file that contains the data you want to analyze.
Make sure that the email address is correct and then send the file.	Tap the "share" button in the upper right. Choose "email" and send the file to yourself.

iPhone	**Android**
On the computer, open the email with the .CSV file. Save the .CSV attachment and open it in Microsoft Excel. **TA CHECKPOINT: Have your TA check your spreadsheet to ensure that you have enough data.** You are interested in graphing acceleration (*on which axis?*) versus time. First, select the "recordtime" column and then, holding down the CTRL key (or the command key on a Mac), click on the column that contains the accelerometer data you want. At the top of the computer screen, click the "Charts" tab. Click "scatter" and then "straight lined scatter".	On the computer, open the email with the .CSV file. Save the .CSV attachment and open it in Microsoft Excel. **TA CHECKPOINT: Have your TA check your spreadsheet to ensure that you have enough data.** You are interested in graphing acceleration (*on which axis?*) versus time. First, select the "Time since start in ms" column and then, holding down the CTRL key (or the command key on a Mac), click on the column that contains the accelerometer data you want. At the top of the computer screen, click the "Charts" tab. Click "scatter" and then "straight lined scatter". You may need to switch the horizontal and vertical axes. You can ask your TA for help with this.

5. ✎ Record the flight time in the table below.

6. Repeat the drop two more times (using the same method as before), using the heights shown in the table below.

7. Record your *experimental* values from your smartphone accelerometer data below. (In other words, do *not* calculate the values nor use a stopwatch to obtain the data for the table below.)

height (m)	time of flight (s)
1.0	
0.75	
0.50	

8. Calculate your experimental value for g. Use linear regression, a common mathematical method for analysis of this sort.
☞ *See the document about linear regression if you're not sure how to do this.*

Lab 2, WebAssign

MT Lab 2 - Free Fall F14 (6304401)

Current Score: 0/100 **Due:** Fri Sep 12 2014 12:15 PM EDT

Question	1	2	3	Total
Points	0/10	0/45	0/45	0/100

Description
You will then subject your device to a cushioned free fall and use its accelerometer data to determine an experimental value for the acceleration due to gravity.

Instructions
Link to Instructions
Link to Concepts and Equations
VPython Instructions

1. 0/10 points MT Lab 1 Group Roles [2694084]

Group Roles

Before you start the lab, identify who on your team will assume roles shown below. If necessary, read the descriptions of Group Roles for Labs.

Lab Manager Manager's Name
Recorder Recorder's Name
Skeptic Skeptic's name

2. 0/45 points MT Lab 2 Free Fall Data - F14v2 [3147833]

Use the exact values you enter to make later calculations. Include units in your answers. More information.

Make sure to read the instructions before beginning to make sure you're doing this correctly!

Initial Drop—Data and Prediction

Upload your sketch of a versus t while the smartphone is in free-fall.
Choose File No file chosen
Key:

Record the height for your initial drop.
1 m

TA Checkpoint!

TA Approval:

Using the equations of uniformly accelerated motion, what do you *predict* the fall time should be?
0.452 s

Record the *measured* fall time using the accelerometer data.
0.452 s

Series of Drops—Data

Record your height and fall time measurements below.

See the instructions for an important note about these values.

[redacted] to the table starting with the largest height value and going in order of decreasing height. (Do not include units in your answers.)

Table 1

Height (m)	Fall Time (s)
________ 1	________ 0.451523640985731
________ 0.75	________ 0.391
________ 0.5	________ 0.319

Calculations and Analysis

What is your experimental value for *g*? (See Linear Regression if you need help with this section.)

9.81 m/s^2

What is the percent error in the experimental value of *g*?

0 %

If you did not get an exact value of 9.81 m/s^2 for *g*, what factors might have contributed to the error? Does this account for your difference (as in, would the factors you identify make your calculated value of *g* larger or smaller than it actually is, and is that consistent with what you measured)?

Key: Most obvious causes are presence of air resistance (should cause a smaller g value than actual) and inaccuracy of the timer start/stop (could go either way).

Suppose instead that we asked you to use traditional equipment (like a handheld stopwatch) to measure the fall time of an object. Do you think it's more accurate to use the smartphone's accelerometer or the stopwatch to determine the fall time of an object? Why?

Key: The smartphone's accelerometer is much more accurate than a handheld stopwatch primarily because the handheld stopwatch will be affected by human reaction time.

3. 0/45 points NCSUCalcPhysMechL3 2.VP.001. [2686666]

Turn in your VPython program below.

- Before turning in your program, compare your running program to that of another group, and then show your running program to your TA.
- Make sure you turn in a working version of your program since you will not receive credit if the program doesn't run. It's a good idea to run your program one last time just before turning it in.
- Sometimes students accidentally turn in the wrong file, or an empty file. To prevent this, after turning in the file, click on its name and make sure the file looks right.

Upload your program. (Submit a file with a maximum size of 1 MB. The file name should have the extension ".py". For example, your file name could be "spring-mass.py".)

Choose File No file chosen

Key: Answers may vary.

Additional Materials

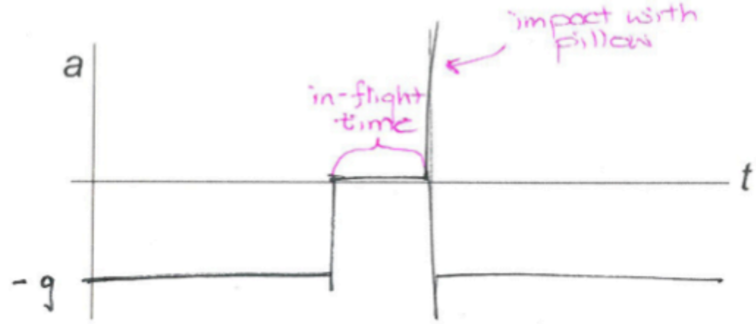
Modeling Free Fall

Assignment Details

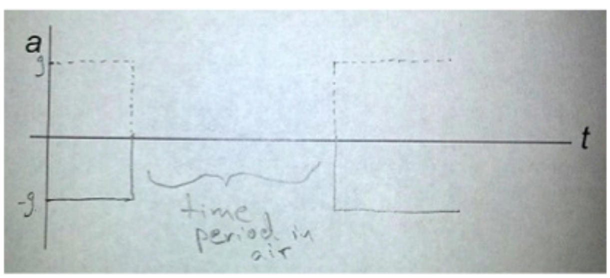
Lab 2, Student Responses to MyTech Questions

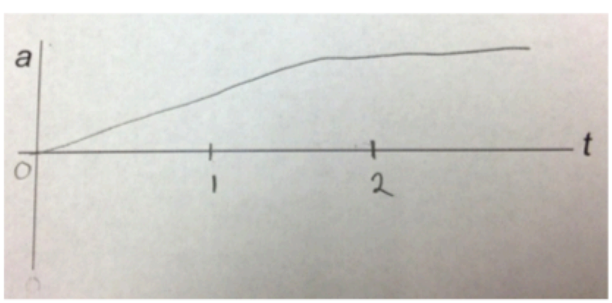
1. ✎ Sketch what you think the acceleration versus time graph will look like when the smartphone is in free fall in the space provided.
☞ *Be sure to label the time period that the phone is in the air. Your sketch need not have a scale for time.*

Key

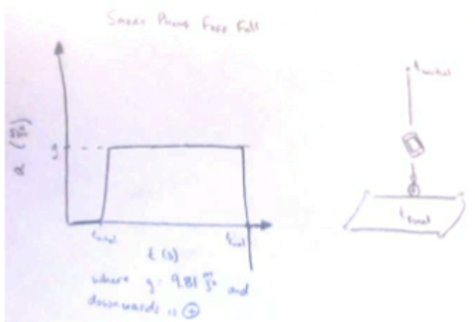


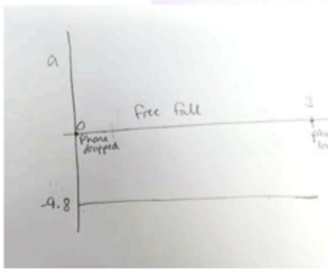
Fall 2013 Responses

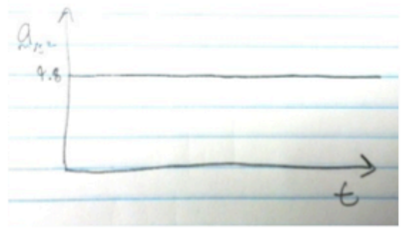




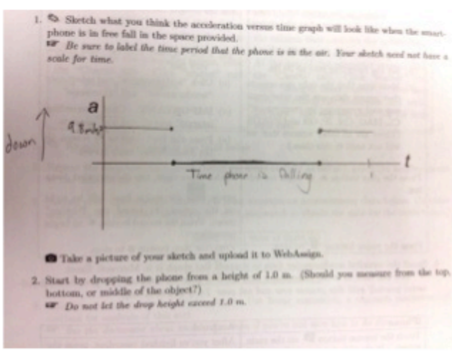
Spring 2014 Responses

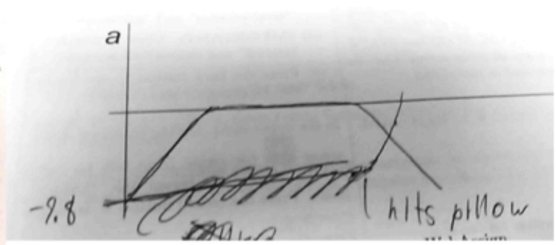






Fall 2014 Responses





- **Question:** Suppose instead that we asked you to use traditional equipment (like a handheld stopwatch) to measure the fall time of an object. Do you think it's more accurate to use the smartphone's accelerometer or the stopwatch to determine the fall time of an object? Why?
- **Key:** The smartphone's accelerometer is likely more accurate than a handheld stopwatch primarily because the handheld stopwatch will be affected by human reaction time.

11.1.Smartphone	Stopwatch
11.2.4	0

- "The smart phone would be more accurate because it compares the acceleration and time together rather than just assuming a start and end time. The stop watch provides more room for human error."
- "…we would have to observe when the phone fell and then arbitrarily determine when to have the beginning and end of the time interval of the fall, while the phone has the time synchronized constantly to the accelerometer for greater accuracy."

Lab 3, Procedure

There are separate handouts about the concepts and equations used in this lab, and for the computer modeling part of the lab.

1 Equipment

Equipment: track, fan, cart, webcam, Movie Maker and Tracker software

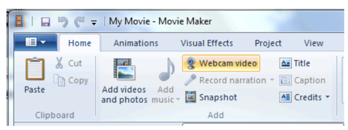
2 Setup for Constant Force

Today, you will not use your smartphones. Instead you will use a webcam to record video of the motion of a cart being pushed with a constant force. You will then analyze it using Tracker software to obtain graphs of position versus time and velocity versus time.

Place the track on the floor. Attach the fan to the cart and place the fan-cart on top of the track. Turn the fan on and try to get a sense of what direction the fan-cart will move.

1. Open Movie Maker by clicking on the Start menu, then typing “Movie Maker”. Press “enter” to open it. Accept the agreement.

2. At the top of the screen, click the “Webcam video” button.



3. After a moment you should see the webcam’s input. Position the webcam so that you can clearly see a significant portion of the cart’s motion down the track. Position the fan-cart so that it will move from left to right across the screen.
   ☞ *Do not hand-hold the webcam! It is very important that the image is very steady!*
   ☞ *You may consider stabilizing the webcam with masking tape or a weight.*

4. Position a meterstick in the frame so that you can make out at least some of the values on it.
   ☞ *The meterstick’s “0” position need not line up with the initial position of the fan-cart.*
   ☞ *Decide what portion of the fan-cart you want to focus on and use as the fan-cart’s position. (Use the center? the front bumper?)*

5. Turn the fan on and record its motion.
☞ *Be prepared to "catch" the cart at the end of the track so that it doesn't collide with anything!*
☞ *Try not to record any more video than you need. It will take longer to analyze and will provide no more new information.*
☞ *You can also use the spacebar to start and stop recording.*

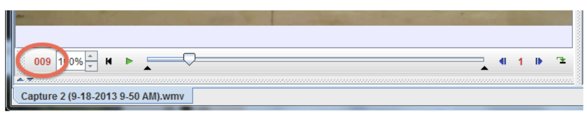
6. When you have finished recording, press the "stop" button. Make a note of where you save the video.

7. Close out of Movie Maker (press "no" when asked to save changes to My Movie) and open Tracker.

8. Open the File Menu. Then select File | Import | Video... Open your video file.
☞ *If you receive a message that tells you "Some frame durations differ from the mean by more than 20%...", press "OK".*

9. Now we want to specify what frames of the movie we will analyze. We are going to tell Tracker the position of the cart at each frame of the movie.

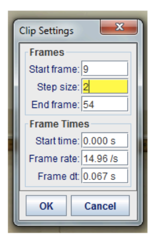
   (a) Using the arrow keys, navigate to the frame of the clip where the fan-cart *just* begins to move. Make a note of what frame you will start with.



   (b) Then, using the slider bar, navigate to the last frame where the fan-cart is visible. Make a note of this frame number.

   (c) Display the clip settings by clicking the "Clip Settings" button on the toolbar.

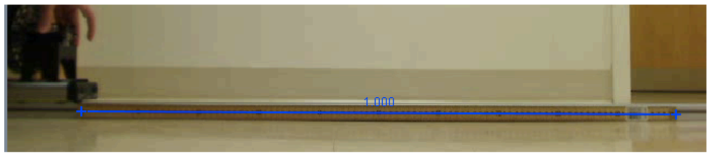
   (d) Enter in the start and end frames and change the "step size" to 2 (so that you will have to analyze fewer frames). Click "ok".



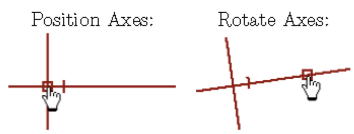
10. Click the "calibration" button and select "calibration stick".

11. Drag the ends of the calibration stick to the ends of your meter stick (or to two points on the meter stick for which you know the distance between). Then click the readout to select it and

enter the known length (without units). In the photo below, I used the entire meterstick and so I entered "1" (where the "m" is implied). We now know that any distance measurement that Tracker outputs will be in meters.



12. Click the "axes" button to show coordinate axes. Drag the origin to the initial position of the object. You can also rotate the axes slightly by dragging the x-axis around.
☞ *You will now want to choose a part of the the cart that you want to "track." I have chosen the "front bumper" and thus have aligned my coordinate axes with the front bumper's initial position.*

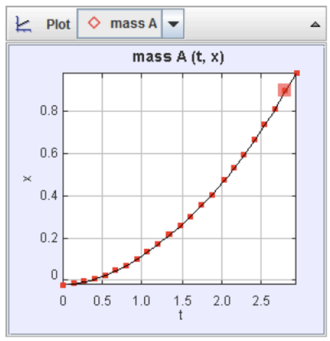


13. Click the "Create" button and choose "point mass."

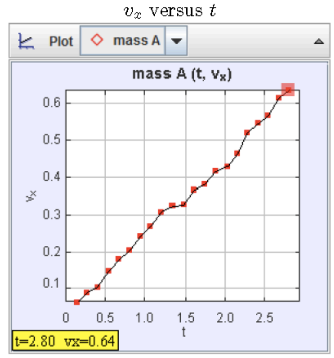
14. When tracking an object, mark its position on every frame by holding down the shift key and clicking the mouse as the video automatically steps through the video clip. Don't skip frames!
☞ *Make sure that you always track the same part of the cart. I used the front bumper.*
☞ *It's very important that you take your time with this portion! The majority of your data will come from this step.*
☞ *You can go back and adjust the position on certain frames by dragging the marked position and nudging it with the arrow keys. You can right-click the video to zoom in for sub-pixel accuracy.*

15. Plot and analyze the tracks. Ideally, your two plots for x versus t and v_x versus t should resemble those below:

x versus t



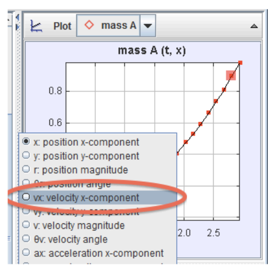
v_x versus t



(a) Right-click in the x versus t plot window. In the submenu that appears, select "Snapshot..."

(b) In the new window that appears, choose File | Save As | png... Make a note of where you save this. Upload the final snapshot to WebAssign.

(c) In the plot window of x versus t, click on the "x" and from the menu that appears, choose v_x. Repeat the two steps above to create and upload a snapshot of the velocity.



16. Answer the following questions:

In which direction (right or left) is the positive x-axis?

For positive v_x, what direction should the cart move?

What do you have to do to make the graph of x versus t a horizontal line?

What do you have to do to make the graph of v_x versus t a horizontal line?

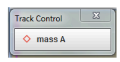
3 Speed Increasing

We have already seen what happens when the cart is subjected to a constant force provided by a fan. Constant force implies a constant acceleration.

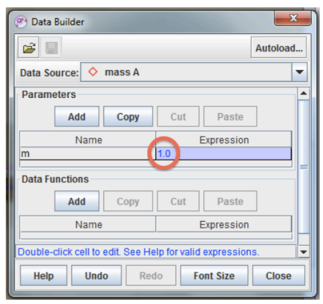
- Describe the shape of the v_x versus t that you expect.
- Does your data match your prediction? What differences are there and why do they exist? Which should you really "believe"?

We now want to find the Δp_x for various intervals. Tracker can calculate this for us.

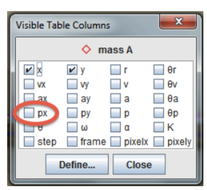
1. Since $p = mv$, we must first tell Tracker the mass of the fan-cart. Use the scale in your classroom to weigh the fan-cart and make note of its mass. In the "Track Control" panel, click "mass A" and the select "Define...".



   In the m parameter, enter the mass of the fan-cart in kilograms.



2. In Tracker's "Table" window, click the word "Table" to open a menu for "Visible Table Columns". Select "px" and click "close".



- In a one-second interval, what is Δp_x?
- In a two-second interval, what is Δp_x?
- What is the net force acting on the fan-cart during each of these intervals?

4 Force opposite to initial velocity

Orient the cart so that the force of the air on the fan-cart is in $+x$ direction. Turn on the fan, start recording a new video, and then given a cart a shove in the $-x$ direction.

✎ Save your x versus t and v_x versus t graphs. Upload them to WebAssign.

✎ in a one-second interval while the cart is moving in the $-x$ direction, what is Δp_x? Make sure your sign is correct.

✎ In a one-second interval while the cart is moving in the $+x$ direction, what is the Δp_x? Make sure your sign is correct.

✎ What is the net force acting on the fan-cart during each of these intervals?

5 Conceptual Questions

✎ Assuming the force on the fan cart due to the air is constant, should Δp_x over a one-second interval be the same for the cart heading in the $+x$ and $-x$-directions? Why or why not? Clearly explain your reasoning about this.

✎ Now look at your data. Is Δp_x over a one-second interval the same for both the $+x$ and $-x$-directions? If not, are there any other forces that could account for this? Clearly explain your reasoning.

✎ Explain your observations in sections 2.1 and 2.2 in terms of the Momentum Principle or Newton's 2nd Law.

Lab 3, WebAssign

MT Lab 3 -Uniformly Accelerated Motion (4783125)

Current Score: 0/100 **Due:** Fri Sep 19 2014 12:15 PM EDT

Question	1	2	3	4	5	Total
Points	0/5	0/35	0/20	0/20	0/20	0/100

Instructions

Concepts

Instructions

VPython Instructions

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1. 0/5 points — MT Lab 1 Group Roles [2694084]

Group Roles

Before you start the lab, identify who on your team will assume roles shown below. If necessary, read the descriptions of Group Roles for Labs.

Lab Manager [ ] Manager's Name

Recorder [ ] Recorder's Name

Skeptic [ ] Skeptic's name

---

2. 0/35 points — Lab 3- Constant Force and Opposite Force [2705836]

Use the exact values you enter to make later calculations. Include units in your answers. More information.

Constant Force

Before you begin, watch this short video on how to assemble the track.

(If the video does not appear automatically above, you may simply use this link to see the video.) Upload your x versus t graph. (Submit a file with a maximum size of 1 MB.)

Choose File No file chosen

Key: Answers may vary.

Upload your v versus t graph. (Submit a file with a maximum size of 1 MB.)

Choose File No file chosen

Key: Answers may vary.

Record the initial conditions needed to produce this graph.

initial direction of motion	---Select--- ✖	+x
direction of force	---Select--- ✖	+x

What do you have to do to make the graph of x versus t a horizontal line?

Key: The object should remain stationary.

What do you have to do to make the graph of v versus t a horizontal line?

Key: The object should move at a constant velocity.

Record Δp_x for the one-second interval.

✖ 0.025 kg*m/s

Record Δp_x for the two-second interval.

✖ 0.05 kg*m/s

Record the net force during the one-second and two-second intervals. (Indicate the direction with the sign of your answer.)

one-second interval	✖	0.025 N
two-second interval	✖	0.025 N

Force Opposite to Initial Velocity

Upload your x versus t graph. (Submit a file with a maximum size of 1 MB.)

Choose File No file chosen

Key: Answers may vary.

Upload your v versus t graph. (Submit a file with a maximum size of 1 MB.)

Choose File No file chosen

Key: Answers may vary.

Record the initial conditions needed to produce this graph.

initial direction of motion	---Select--- ✖	−x
direction of force	---Select--- ✖	+x

Record Δp_x in a one-second interval while the cart is heading in the $-x$ direction.

✖ 0.025 kg*m/s

Record Δp_x in a one-second interval while the cart is heading in the $+x$ direction.

✖ 0.025 kg*m/s

Record the net force during the $-x$ and $+x$ intervals. (Indicate the direction with the sign of your answer.)

$-x$ interval	✖	0.025 N
$+x$ interval	✖	0.025 N

3. 0/20 points NCSUCalcPhysMechL3 3.IL.002. [2689390]

Analysis

Answer the following questions as a group. Make your answers brief (a few sentences) but clear.

Assuming that the force on the fan cart due to the air is constant, should Δp_x over a one-second time interval be the same in both situations (cart heading in $+x$ and $-x$ directions)? Why or why not? Clearly explain your reasoning about this, then check with another group.

Key: If the force of the air on the cart stays constant, and if that is the only force in the horizontal direction, then the x-component of that force should be the same regardless of whether the cart moves in the $+x$ or $-x$ direction. Then Δp_x over the same amount of time should be the same when moving in the $+x$ or $-x$ direction. Δp_x for both cases should be negative.

Another way to say this is that if F_x is constant, then $\frac{\Delta p_x}{\Delta t}$ should be constant too, from the momentum principle. Since $p_x = mv_x$ in this case, then $\frac{\Delta v_x}{\Delta t}$ or the slope of the v_x vs. t graph should be constant, and negative.

From your data, do you get the same value or different values for Δp_x over a one-second time interval in the two situations? What can you conclude from your observations?

Key: The Δp_x values over a one-second interval are different for the two different cases. They are both negative, but the magnitude of Δp_x is greater when moving in the $+x$ direction than in the $-x$ direction.

The reason is the friction force acting on the cart. The force due to the air is constant when moving in either direction, but the friction force is not. The friction force points in the opposite direction of the cart's momentum. So when the cart is moving in the $+x$ direction, both the force of the air and the friction force are in the $-x$ direction. When the cart moves in the $-x$ direction, the force of air is in the $-x$ direction, but the friction force is in the $+x$ direction, making the net force magnitude slightly smaller in this direction. Therefore, the magnitude of Δp_x over the same time interval is slightly smaller when moving in the $-x$ direction.

Clearly explain your observations in the Increasing Speed and Force Opposite to Initial Velocity sections from the lab in terms of the Momentum Principle or Newton's 2nd Law.

Key: No net force produces constant velocity and so the change in momentum is zero (a flat graph).

Increasing Speed: A constant net force causes a constant change in momentum (a straight line with constant slope). If the force is in the same direction as the motion ($+x$), the velocity will be positive with a positive slope.

Force Opposite to Initial Velocity: Since the net force is a different constant for the different intervals, the slope of the graph will be steeper when the force is greater and shallower when the force is less. However, the slope will always be negative since the net force is in the $-x$ direction.

Supporting Materials

DataStudio Setup File

Additional Materials

Momentum and Uniformly Accelerated Motion - Concepts
Momentum and Uniformly Accelerated Motion - Procedure

4. 0/20 points NCSUCalcPhysMechL3 3.VP.001. [2689386]

Answer the question from part 7 of the VPython instructions here.

Key: The graph in the simulation has a constant slope, whereas the experimental graph changed slope after the cart turned around. The difference is that the simulation does not simulate friction or air resistance, so the graph's slope is simply the force due to the air (a constant), whereas the slope in the experiment is the sum of the fan force and resistive forces while the cart slows down, and the difference between those forces as it speeds up.

5. 0/20 points NCSUCalcPhysMechL3 3.VP.002. [2689387]

Turn in your VPython program below.

- Before turning in your program, compare your running program to that of another group, and then show your running program to your TA.
- Make sure you turn in a working version of your program since you will not receive credit if the program doesn't run. It's a good idea to run your program one last time just before turning it in.
- Sometimes students accidentally turn in the wrong file, or an empty file. To prevent this, after turning in the file, click on its name and make sure the file looks right.

Upload your program. (Submit a file with a maximum size of 1 MB. The file name should have the extension ".py". For example, your file name could be "spring-mass.py".)

Choose File No file chosen

Key: Answers may vary.

Assignment Details

Lab 4, Procedure

1 Purpose

In this lab, you will analyze the motion of a cart rolling into a spring on a track and bouncing back. In first portion of this lab, you will verify the equation

$$\vec{F}_{\text{net}} = \frac{\Delta \vec{p}}{\Delta t}. \quad (1)$$

In the second portion of this lab, you will verify that the impulse, which is defined as $\vec{J} = \int \vec{F}\, dt$, also satisfies the following equation:

$$\vec{J} = \int \vec{F}\, dt = \Delta \vec{p}. \quad (2)$$

In this lab you will:

- use your smartphone's accelerometer to determine the force (since $\vec{F}_{\text{net}} = m\vec{a}$) in equations (1) and (2),
- use Tracker software to analyze the motion of the cart and determine $\Delta\vec{p}$ in equations (1) and (2),
- and use your measurements to relate impulse to change in momentum.

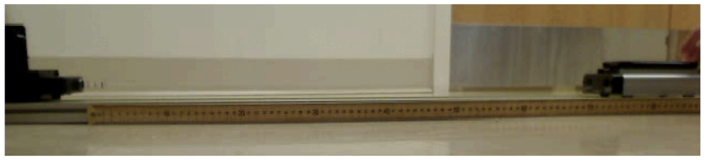
2 Experimental Setup

Equipment: track, cart, smartphone with accelerometer app, webcam, Tracker software, soft spring with bracket, balance.

2.1 Equipment setup

- Place your smartphone gently on top of the cart.
  ☞ *You may want to consider securing the smartphone by placing a rubber band around the cart-phone ensemble.*

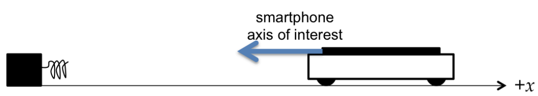
- On the computer, open the Movie Maker software. Click the "webcam" button.
- Position the webcam so that about 1 m of the track and the spring with bracket are in the field of view.



- Ensure that the *soft* spring is attached to the bracket. If a different object is attached, take it off and put it into an empty slot in the mounting bracket, then attach the spring to the front of the bracket.

Answer the following questions:

✎ What is the axis of interest *on the smartphone* as it moves toward and away from the spring? (In other words, which smartphone axis' data are you most interested in analyzing?)



✎ The accelerometer output of the smartphone will give you $\vec{a}$. What equation can you use to determine the force on the smartphone from $\vec{a}$?(In other words, what fundamental equation relates $\vec{F}$ and $\vec{a}$?)

✎ Sketch what you predict to see in the **accelerometer output** of the smartphone as the cart rolls toward the spring and then bounces back off of the spring in the space provided below.
☞ *You may want to consider the acceleration of the device (1) as it rolls toward the spring, (2) as it compresses the spring, (3) as the spring extends and (4) as the cart travels back up the track.*
📷 Take a picture and upload it to WebAssign.

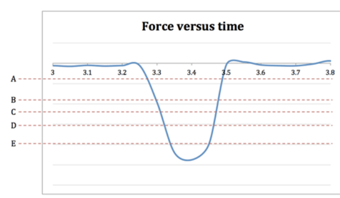
✎ Sketch what you predict to see in the **momentum output** from Tracker as the cart rolls toward the spring and then bounces back off of the spring in the space provided below. 📷 Take a picture and upload it to WebAssign. ☞ *Momentum and force are not the same, so you should not expect your graph below to match the one above!*

2.2 Note about reciprocity of forces

The interaction between the cart and the spring is due to electric interactions between the protons and electrons in the cart and those in the spring. It is a property of the electric interaction that the electric forces exerted by two objects on each other are equal and opposite. Therefore, the graph of F on the *spring* versus t would be the same as the one you see, but the values of F be negative.

2.3 Average Force

Clearly, F in this experiment is not constant; it varies with time. However an *average* value of F can be estimated by examining your accelerometer graph.



☞ *Note: Depending on the way in which you oriented your smartphone (and the way the axes are oriented on your smartphone), you may obtain a similar graph that has been "flipped" along the horizontal axis.*

- First, discuss with your group why F is *not* constant. Clearly explain your reasoning.
- Examine the sample graph above and discuss, with your group, which value (A, B, C, D, or E) best represents the *average* value of F.

3 Simultaneous measurement of F and Δp

Use your equipment to measure F versus t and v versus t while the cart rolls toward the spring, collides with the spring and bounces off, rolling backward toward your hand.
IMPORTANT: You will *simultaneously* take data with the smartphone accelerometer and the webcam. You may need to practice your experimental method once or twice before feeling comfortable taking "real" data.
☞ *Do not push the cart so quickly that the smartphone falls of the cart upon impact with the spring!*

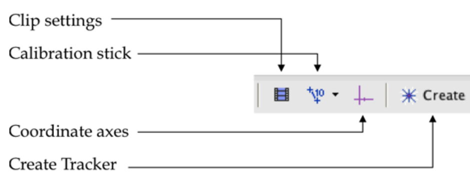
1. Open the sensor app on your smartphone and, with the phone resting on top of the cart, begin recording acceleration data.
   ☞ *Be sure that the recording rate is on the fastest setting so that you can collect data with the highest time resolution possible.*

2. Begin recording on the webcam in Movie Maker.

3. Push the cart into the spring (but not so forcefully that the smartphone falls off of the cart upon impact with the spring).

4. Stop recording both in Movie Maker and on the sensor app.

5. Import the webcam video into Tracker and, using the same procedure as last time ...



   (a) use the "clip settings" button to define the start and end frames of the carts motion.
   ☞ *Make sure to define the start frame as immediately after your hand leaves the cart and define the end to be long after the cart makes contact with the spring. Also, define the step size as "2" to save your some work during the tracking process.*
   (b) Create a new calibration stick and define a length in meters on screen,
   (c) position and rotate the coordinate axes so that it lines up with the track,
   (d) create a point mass tracker,
   (e) and, by holding the "shift" button while clicking, track the cart as it moves back and forth on the track.

6. Record the mass of the cart and smartphone ensemble and enter it in to Tracker.

7. Change the axes on the graph in Tracker so that it displays p_x versus t. Save the snapshot as a .png and upload it to WebAssign.

8. On the computer, open your accelerometer data in Microsoft Excel and calculate the force experienced *by the smartphone.*

(a) Create a new column for the force F (in the direction that you determined at the beginning of the lab).

(b) **Be sure to account for the sign change** that may or may not take place, depending on the orientation of your smartphone on the cart. The axes for acceleration should be consistent with those used in Tracker.

(c) Also, be sure that if your phone has measured the acceleration in units of g, that you have converted this into $\frac{\mathrm{m}}{\mathrm{s}^2}$.

(d) Graph F_x versus t.
☞ *Double-click the "Horizontal (Value) Axes" and select the "Scale" tab to adjust the maximum and minimum values so that you can "zoom in" on the area of interest.*

(e) Right-click your Excel graph, save it as a .png and upload it to WebAssign.

4 Analysis of motion

Complete the following analyses with your group members:

✎ From the graph of p_x versus t generated by Tracker, determine the change in the cart's momentum from just before the collision starts to just after it ends. Record this as Δp_x.

✎ From the graph of F_x versus t generated by the accelerometer, estimate the total duration of the collision, Δt.

✎ From the graph of F_x versus t generated by the accelerometer, estimate the average value of F_x during this interval.

✎ Using the average value, estimate the impulse, $F_{x,\mathrm{avg}}\Delta t$, applied by the spring on the cart during the collision (with the correct sign). This method approximates the integral $\vec{J} = \int \vec{F}\,dt$.

✎ How does your calculated value of Δp_x compare to your estimated value of $F_x \Delta t$?

✎ How would you expect these values to compare?

5 Important questions to answer

✎ How does the x component of the net impulse found using your estimate of $\int F_x\,dt$ compare to the x component of the change in the cart's momentum?

✎ When F_x is the biggest (in magnitude) it ever gets, what is p_x? Is p_x also at a maximum (in magnitude)? Is p_x proportional to F_x? Relate your answers to the Momentum Principle.

Lab 4, WebAssign

MT Lab 4 - Impulse and Momentum S14 (6419995)

Current Score: 0/58 **Due:** Fri Sep 26 2014 12:15 PM EDT

Question	1	2	3	4	5	**Total**
Points	0/3	0/6	0/9	0/20	0/20	**0/58**

Instructions

Concepts

Instructions

VPython Instructions

Be sure to expand out all sections of the WebAssign assignment!

---

1. 0/3 points MT Lab 1 Group Roles [2694084]

Group Roles

Before you start the lab, identify who on your team will assume roles shown below. If necessary, read the descriptions of Group Roles for Labs.

Lab Manager		Manager's Name
Recorder		Recorder's Name
Skeptic		Skeptic's name

---

2. 0/6 points MT Lab 4 Eq Setup [2708426]

If you haven't already, please watch the short video on how to collect data in this lab.

Equipment Setup

What is the axis of interest *on the smartphone* as it moves toward and away from the spring?

---Select--- *y*

The accelerometer output of the smartphone will give you ***a***. What equation can you use to determine the force on the smartphone from ***a***?

Key: F=ma; Newton's Second Law

Upload your sketch of the predicted accelerometer output.

Choose File No file chosen

Key: Answers may vary.

Upload your sketch of the predicted momentum output from Tracker.

Choose File No file chosen

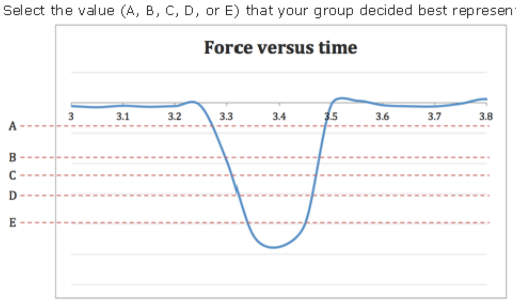
Key: Answers may vary.

Average Force

Why is F_x not constant? Clearly explain your reasoning.

Key: As the spring is compressed, the force acting on the cart increases in magnitude.

Select the value (A, B, C, D, or E) that your group decided best represents the average force from the sample graph.



- A
- B
- C
- D
- E

Use the exact values you enter to make later calculations. Include units in your answers. More information.

Data

Enter your initial time.

2 s

Enter your final time.

2.5 s

Enter the momentum of the cart at your initial time.

0.2 kg*m/s

Enter the momentum of the cart at your final time.

-0.2 kg*m/s

Calculations

Enter your estimate for the average value of $|F_x|$.

4 N

Given your values for initial and final momentum of the cart and the momentum principle, what would you expect the **magnitude** of the area under the F_x vs. t curve to be?

0.4 kg*m/s

Using your estimate for the average value of $|F_x|$, enter your estimate of the area under the F_x vs. t curve here. (Your answer should be a positive number.)

2 kg*m/s

Upload your accelerometer graph from Microsoft Excel.

Choose File No file chosen

Key: accelerometer file upload

Upload your momentum graph from Tracker.

Choose File No file chosen

Key: momentum file upload

4. 0/20 points NCSUCalcPhysMechL3 4.IL.003. [2689393]

Analysis

How does the x-component of the net impulse found using $\int F_x dt$ compare to the x-component of the change in the cart's momentum? (Remember that the actual value of the impulse applied to the cart is negative).

Key: Answers may vary.

When F_x is the biggest it ever gets, what is p_x? Is p_x also at a maximum? Is p_x proportional to F_x? Relate your answers to the Momentum Principle.

Key: Answers may vary.

Supporting Materials

DataStudio Setup File

Additional Materials

Measuring Impulse and Momentum Change in 1 Dimension - Concepts
Measuring Impulse and Momentum Change in 1 Dimension - Procedure

5. 0/20 points NCSUCalcPhysMechL3 4.VP.001. [2689395]

Turn in your VPython program below.

- Before turning in your program, compare your running program to that of another group, and then show your running program to your TA.
- Make sure you turn in a working version of your program since you will not receive credit if the program doesn't run. It's a good idea to run your program one last time just before turning it in.
- Sometimes students accidentally turn in the wrong file, or an empty file. To prevent this, after turning in the file, click on its name and make sure the file looks right.

Upload your program. (Submit a file with a maximum size of 1 MB. The file name should have the extension ".py". For example, your file name could be "spring-mass.py".)

Choose File No file chosen

Key: Answers may vary.

Assignment Details

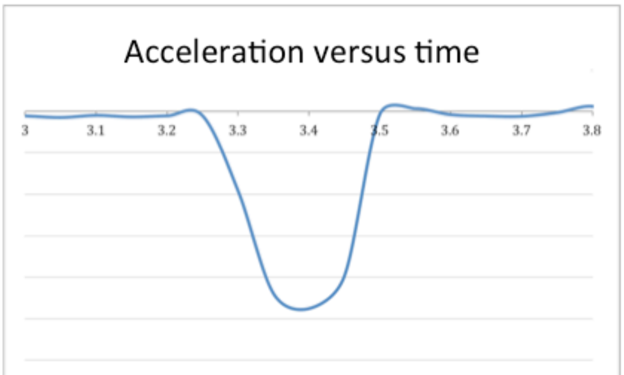
Lab 4, Student Responses to MyTech Questions

Sketch what you predict to see in the **accelerometer output** of the smartphone as the cart rolls toward the spring and then bounces back off of the spring in the space provided below.

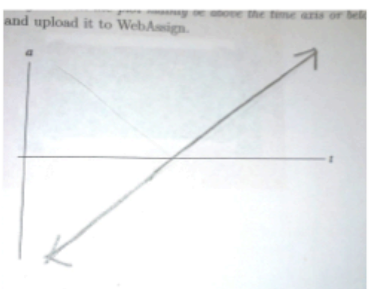
You may want to consider the acceleration of the device (1) as it rolls toward the spring, (2) as it compresses the spring, (3) as the spring extends and (4) as the cart travels back up the track.

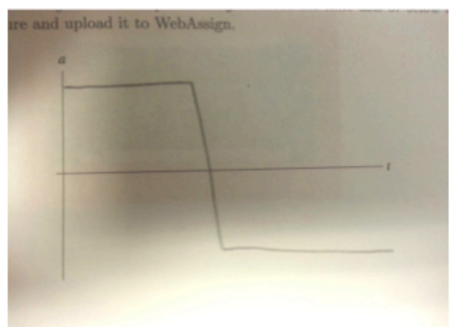
Take a picture and upload it to WebAssign.

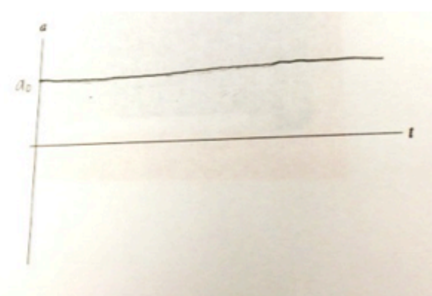
Key



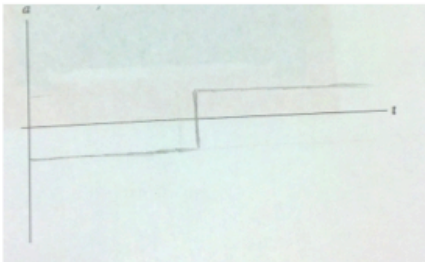
Fall 2013 Responses

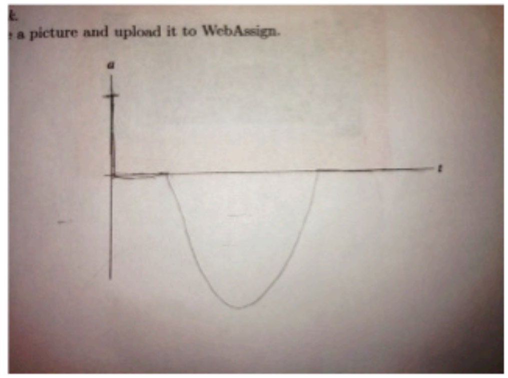


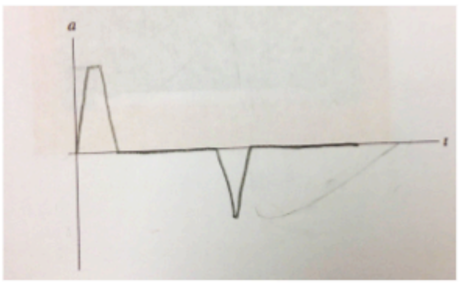


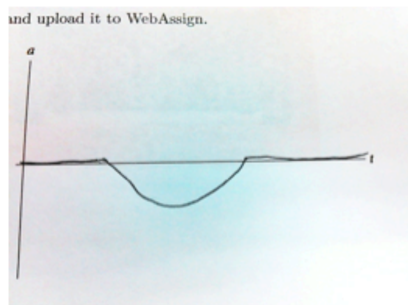


Fall 2014 Responses



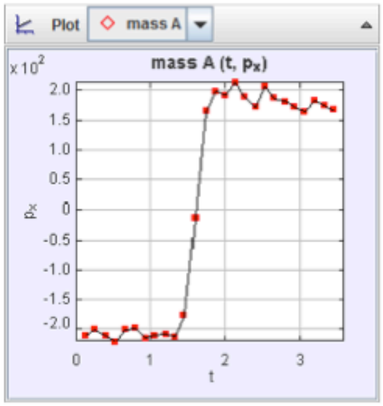




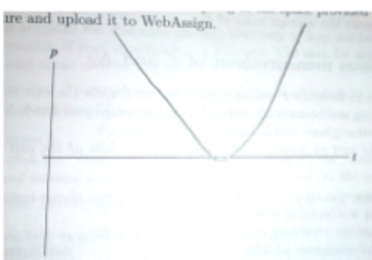


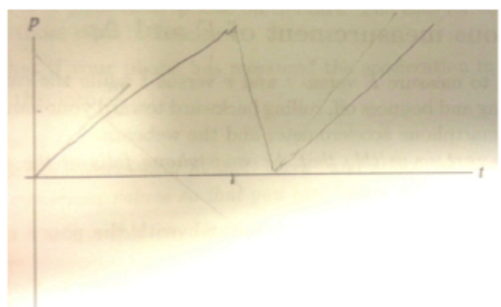
✎ Sketch what you predict to see in the **momentum output** from Tracker as the cart rolls toward the spring and then bounces back off of the spring in the space provided below. 📷 Take a picture and upload it to WebAssign. ☞ *Momentum and force are not the same, so you should not expect your graph below to match the one above!*

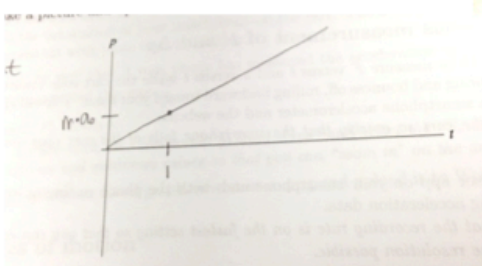
Key

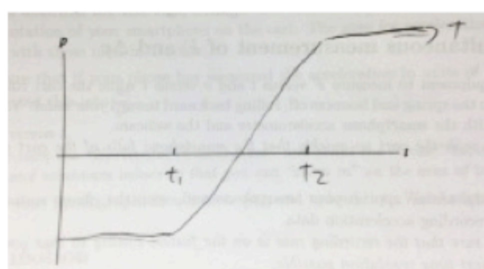


Fall 2013 Responses

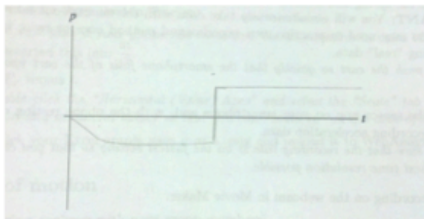


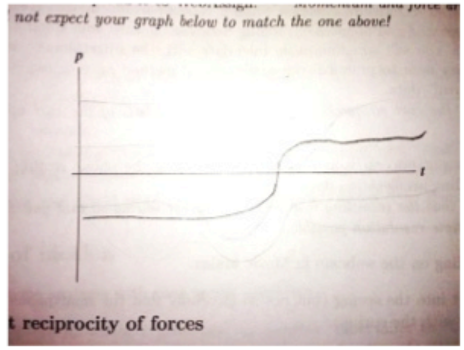


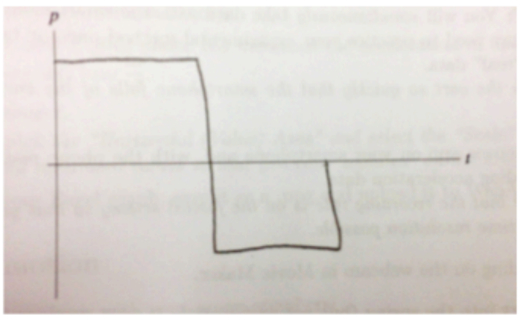


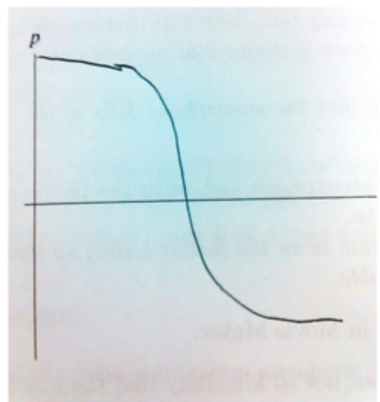


Fall 2014 Responses









Lab 5, Procedure

1 Purpose

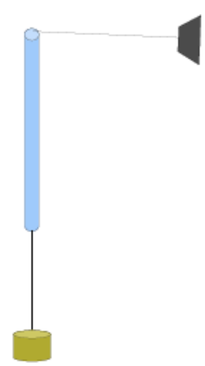
In the first portion of this lab, you will determine the mass of a rubber stopper by attaching a string to it, swinging it over your head and measuring the radius of the arc as well as the period of the swing.

In the second portion, you will also account for the gravitational pull on the rubber stopper to obtain a more accurate measurement of its mass. You will use Tracker software to determine the angle of interest.

2 Set Up the Apparatus

Most of the data collection from the lab will involve the following method:

1. Cut a long piece of string and run it through the steel tube so it sticks out both sides.
2. Tie the rubber stopper to the end of the string on the side of the tube with the white plug. *(This is a Teflon plug designed to reduce friction.)*
3. Tie a loop at the other end of the string. You will hang the mass hanger from this end.
4. To achieve uniform circular motion, hold the tube vertically with the mass hanger (shown in gold below) at the bottom and spin the stopper (shown in black below) around in a circular motion.



5. To give you an idea of what this should look like, here is a YouTube video demonstrating this type of lab: (http://go.ncsu.edu/circmotionlab)

3 Measure the Radius of the Arc and the Average Period

Don't hit any computers or people while spinning the stopper!!!!

To measure the period:

- Use a timing device (such as your smartphone's stopwatch) to record the time for 10 full oscillations.
- Divide the total time for the 10 oscillations by 10 to determine the average period of rotation, T.
  ☞ *Measuring for 10 oscillations is done to minimize the effect of measurement uncertainty.*

To measure mass and arc radius:

- When you're ready to stop spinning the stopper, grab the string so that you can measure the length of it without it sliding to determine L, the arc radius.
- You can use the accepted weights of your hanging masses, or weigh them on the triple-beam balance to determine m_h.
- In general, use whatever values of m_h and L you want.
  ☞ *Mix up different values for m_h to obtain a variety of data.*

Equations and Derivations

Part 1

The principle behind this experiment is that the weight of the hanging mass provides a tension that will provide the centripetal force for the swinging mass. Thus, for a mass moving in a horizontal arc, the weight of the hanging mass, $m_h g$ is equal to the centripetal force on the stopper, $M_s \frac{v^2}{r}$.

The speed of the moving mass can be related to the period of rotation and the radius of the path. Since speed is distance over time for constant speed, the distance of a circular path (the circumference, $2\pi r$) divided by the time to travel the path (the period, T) gives the speed:

$$v = \frac{2\pi r}{T}$$
$$a_c = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$$

In this case, the radius of the path will be L, the length of string between the end of the tube and the stopper.

Note that the centripetal force is being provided by the tension in the string necessary to support the weight of m_h. That is,

$$F_c = F_T = m_h g$$
$$m_h g = M_s a_c$$

This will be useful for calculating M_s from the slope of the trend line.

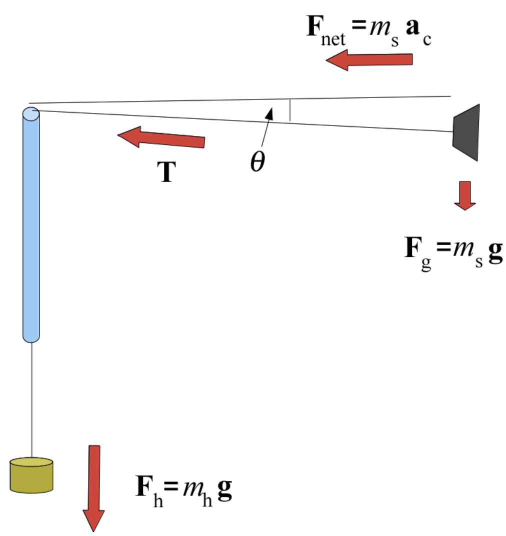
Part 2

In Part 1, an approximation is being made that the only force acting on the stopper is the tension in the string, and so the tension equals the centripetal force. In reality, gravity plays a role in the process as well.

The string will actually be at an angle, as shown in Figure 2 (next page), rather than purely horizontal. In this case, the tension force (calculated with $m_h g$), is the hypotenuse of a right triangle, where the vertical side is the gravitational force on the stopper ($M_s g$) and the horizontal component is the centripetal part $\left(M_s \frac{v^2}{r}\right)$.

This means that when you include gravity, the centripetal force term ($M_s a_c$) is actually equal to only the horizontal component of the tension, $m_h g cos(\theta)$.

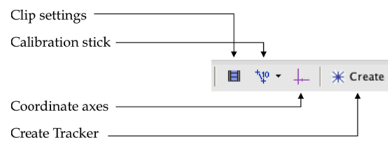
$$M_s a_c = m_h g cos(\theta)$$



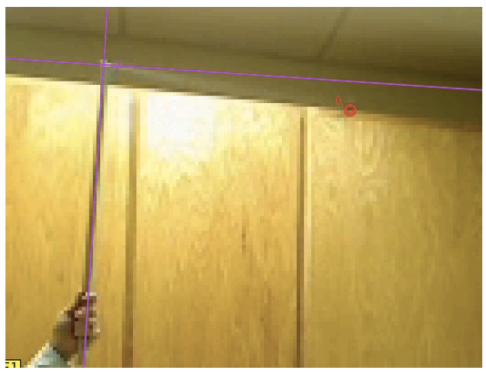
To measure the angle θ,

- Repeat the procedure above once more, this time using your webcam and Movie Maker software to record a video of a group member swinging the apparatus.
  ☞ *Be sure that your webcam will not move during recording! Attach to a fixed surface (like the floor), is possible.* ☞ *The camera and apparatus must be at the same height to measure the angle accurately.*
- Record T, L, and m_h as before.
- Open your recorded video in Tracker.

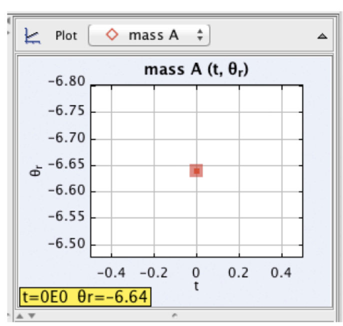
- Find a frame in which you can clearly make out the angle θ and make a note of the frame number.
- Click the "clip settings" button and define the first frame as the frame of interest.
  ☞ *You need not change any other settings, as we are only going to analyze one frame.*



- Click the "coordinate axes" button and arrange the axes so that the vertical axis is aligned with the rod in your apparatus. You will likely need to rotate your axes!
  ☞ *You need not create a calibration stick in your Tracker window as the angle θ is independent of length.*



- Create a point mass and, by shift+clicking (only once), mark the position of the stopper.
- In the plot palette, plot θ_r versus t. (It should only plot one point as we are only analyzing one frame.) Select the point and read off θ_r from the yellow box within the plot palette.



Lab 5, WebAssign

MT Lab 5 - Uniform Circular Motion S14 (6429196)

Current Score: 0/100 **Due:** Fri Oct 3 2014 12:15 PM EDT

Question	1	2	3	4	Total
Points	0/3	0/47	0/20	0/30	0/100

Instructions

Procedure and Concepts

---

1. 0/3 points MT Lab 1 Group Roles [2694084]

Group Roles

Before you start the lab, identify who on your team will assume roles shown below. If necessary, read the descriptions of Group Roles for Labs.

Lab Manager		Manager's Name
Recorder		Recorder's Name
Skeptic		Skeptic's name

---

2. 0/47 points MT Lab 5 Experiment [2725740]

Use the exact values you enter to make later calculations.

Part 1: Experimental Determination of Mass – Data

NOTE: Please *ignore* any mass values written on the rubber stopper. Part of the purpose of this lab is to determine that value. You will not need to enter the value written on the stopper for any reason. (And there's no guarantee it's correct.)

Complete the table below.

Table 1

Trial	T (s)	L (m)	m_h (kg)
1	0.751	1.4	0.5
2	0.867	1.5	0.4
3	0.777	1.5	0.5
4	0.802	1.6	0.5
5	0.733	1.6	0.6

Part 1: Experimental Determination of Mass – Calculations

Complete the table below using values from Table 1 for your calculations.

Table 2

Trial	a_c (m/s^2)	$m_h g$ (N)
1	98	4.91
2	78.8	3.92
3	98.1	4.91
4	98.2	4.91

5	118	5.89

Note that $m_h g$ provides the tension in the cord (because the hanging mass is approximately motionless and thus in equilibrium), so if the stopper is swinging in an approximately horizontal circle, the tension value, $m_h g$, will be the centripetal force, F_c. You can use the values of F_c and a_c to determine the mass of the stopper.

What is the experimental value of M_s, the mass of the stopper, from the slope of the graph of $m_h g$ versus a_c? *See Linear Regression if you need help with this calculation and the lab manual if you're unsure of which equation is relevant.* (Include units in your answer. More information.)

M_s = 0.0506 kg

Part 2: An Alternate Method – Data and Calculations

Perform one more trial, making sure that you have a way of determining the angle, θ. (See the lab manual for details. Include units in your answers. More information.)

T = 0.48 s

L = 0.8 m

m_h = 0.7 kg

What is the magnitude of the angle formed by the string relative to the horizontal during this trial?

10 °

Based on this angle, what is the mass of the stopper? Details about this calculation are in the lab manual. (Include units in your answer. More information.)

M_s = 0.0493 kg

Analysis

What is the percent difference between the two values of M_s?

2.51 %

What factors may contribute to the difference in these two values?

Key: Answers may vary.

Based on the assumptions made and possible sources of error, as well as the accuracy of the data collection methods, which value do you feel is likely to be more accurate? Why?

Key: Answers may vary.

3. 0/20 points NCSUCalcPhysMechL3 5.VP.001.K. [2704340]

Once you're done with your program, answer the following question.

What initial speed (y-component of the initial velocity) did you need to give your craft in order to achieve an approximately circular orbit?

2506 m/s

4. 0/30 points NCSUCalcPhysMechL3 5.VP.002.K. [2704343]

Turn in your VPython program below.

- Before turning in your program, compare your running program to that of another group, and then show your running program to your TA.
- Make sure you turn in a working version of your program since you will not receive credit if the program doesn't run. It's a good idea to run your program one last time just before turning it in.
- Sometimes students accidentally turn in the wrong file, or an empty file. To prevent this, after turning in the file, click on its name and make sure the file looks right.

Upload your program. (Submit a file with a maximum size of 1 MB. The file name should have the extension ".py". For example, your file name could be "spring-mass.py".)

Choose File No file chosen

Key: Answers may vary.

Assignment Details

Lab 6, Procedure

Impulse, Momentum, and Energy

Introduction

Recall that Newton's second law claims that $\vec{F} = m\vec{a}$. Thus,

$$\vec{F} = m\vec{a} = m\frac{d\vec{v}}{dt} = \frac{d(m\vec{v})}{dt} = \frac{d\vec{p}}{dt}.$$

Then, we can rearrange the above equation and define **impulse** as follows...

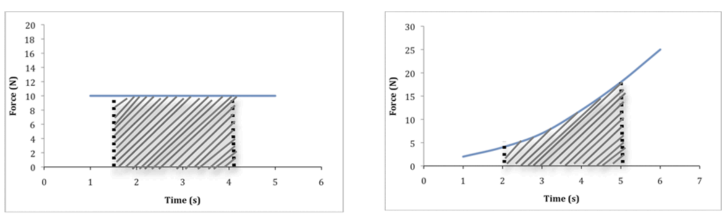
$$\vec{F}_{\text{net}}dt = d\vec{p} \qquad \Longrightarrow \qquad \vec{I} = \int_{t_i}^{t_f} \vec{F}_{\text{net}}\, dt = \vec{p}_f - \vec{p}_i.$$

This equation is known as the **impulse-momentum theorem**. We will verify this equation in this lab by comparing $\int \vec{F_{\text{net}}}\, dt$ and $\Delta\vec{p}$.
We will also use the **work-energy theorem** to calculate the amount of energy lost when a cart bounces into a spring.

Discussion of Principles

Impulse-Momementum Theorem

We can determine the integral of $\int F_{\text{net}}\, dt$ graphically by determining the area beneath an F_{net} versus t curve. Thus, the impulse is the area under the force-time curve as indicated by the shaded region in the graphs below.



(a) (b)

Figure 1: Impulse as area under force-time curve

Work-Energy Theorem

The simplest form of the Work-Energy Theorem states that the change in kinetic energy of an object is equal to the total work done on that object.

$$\Delta K = W \tag{3}$$

The work done can be divided into W_C, the work done by conservative forces like gravity, and W_{NC}, the work done by non-conservative forces like friction, so that Eq. (3) can be written as

$$\Delta K = W_C + W_{NC} \tag{4}$$

Since $W_C = -\Delta U$, where ΔU is the change in the potential energy of the object, this can be rewritten as

$$\Delta K + \Delta U = W_{NC} \tag{5}$$

or

$$\begin{aligned} W_{NC} &= (K_f - K_i) + (U_f - U_i) \\ &= (K_f + U_f) - (K_i + U_i) \\ &= (E_f - E_i) \end{aligned} \tag{6}$$

where E_i is the initial value of the total mechanical energy of the object and E_f is the final value of the total mechanical energy of the object. Therefore,

$$W_{NC} = \Delta E \tag{7}$$

Equation (7) states that the total change in the mechanical energy of an object is equal to the work done by non-conservative forces.

Objective

In this lab, you will verify the impulse-momentum theorem by investigating the collision of a moving cart with a fixed spring. You will also use the work-energy theorem to evaluate the energy losses during the collision.

Equipment

- Track
- Spring bumper
- Cart with low friction wheels
- Meter stick
- Webcam
- Smartphone
- Tracker software
- rubber bands

Procedure

The experimental setup consists of a long, inclined track with a spring at one end, as in Fig. 2. A cart will be released from the high side of the track and will roll down the incline, collide with the spring, and then roll back up the incline.

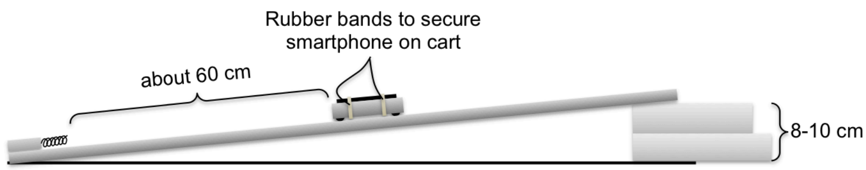


Figure 2: experimental setup

From the lab concepts described above, we know that impulse is defined to be

$$I = \int_{t_i}^{t_f} F\, dt = \Delta p.$$

We will use the smartphone accelerometer as it travels down the track on the cart to determine the force F over time as the cart collides with the spring and thus we will be able to calculate $\int F\, dt$. We will use Tracker software to determine the velocity immediately before and after the collision with the spring, and thus we will be able to calculate Δp. We can then compare these two sides of the equation and attempt to verify the impulse-momentum theorem.

During this process, some of the cart's energy will be lost due to the action of non-conservative forces. You will be able to see this in two ways. First, the initial and final speeds recorded by the photogate will not be equal, indicating that energy is lost due to the action of non-conservative forces during the collision. According to Eq. (7), the energy lost during the collision is equal to the work done by these non-conservative forces.

$$\Delta E_{\text{collision}} = W_{\text{NC}}^{\text{collision}} \tag{8}$$

Secondly, after the collision, the cart will return to a point on the inclined track that is lower than the point from which it was initially released. This shows a net loss of energy over the entire trip. Some of this energy is lost during the collision as shown in Eq. (8), and some is lost to other non-conservative forces acting while the cart travels down and up the ramp. Therefore, the total energy lost during the entire trip will be equal to the work $W_{\text{NC}}^{\text{collision}}$ done by non-conservative forces during the collision, plus the work $W_{\text{NC}}^{\text{traveling}}$ done by the other non-conservative forces acting while the cart travels along the track. In other words,

$$\Delta E_{\text{total}} = W_{\text{NC}}^{\text{collision}} + W_{\text{NC}}^{\text{traveling}} \tag{9}$$

Let's now try to determine these energy losses in terms of quantities that can be determined experimentally. We will first focus on the energy loss that occurs over the entire trip, ΔE_{total}. Figure 3 is a diagram of the trip taken by the cart.

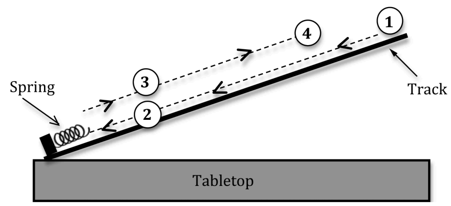


Figure 3: Diagram of the path of the cart

The cart is released from location ①, travels down the ramp and first passes through the photogate at location ② just before the collision. This is represented by the thin dashed line with arrows pointing down the track.

The cart then bounces off the spring and passes back through the photogate at location ③ just after the collision. This is represented by the thin dashed line with arrows pointing up the track. Note that locations ② and ③ are actually the same positions on the track.

Finally, the cart returns to location ④, which is lower on the track than the initial starting location ①. The two dashed lines are displaced from each other for clarity.

Combining Eqs. (5) and (7) we get

$$\Delta E_{\text{total}} = \Delta K_{\text{total}} + \Delta U_{\text{total}} \tag{10}$$

where $\Delta K_{\text{total}} = K_4 - K_1$ and $\Delta U_{\text{total}} = U_4 - U_1$. Since the cart is released from rest and returns to rest, $K_4 = K_1 = 0$ and

$$\Delta E_{\text{total}} = U_4 - U_1. \tag{11}$$

If we focus on determining the energy loss just in the collision itself (i.e., from location ② on the way down back to location ③ on the way up), we have

$$\Delta E_{\text{collision}} = \Delta K_{\text{collision}} + \Delta U_{\text{collision}} \tag{12}$$

where $\Delta K_{\text{collision}} = K_3 - K_2$ and $\Delta U_{\text{collision}} = U_3 - U_2$. Since the cart is at the same height each time it passes through the photogate $U_3 = U_2$ and we get

$$\Delta E_{\text{collision}} = K_3 - K_2. \tag{13}$$

Equations (11) and (13) can be used to determine the total energy loss and the energy loss just in the collision, respectively. Then, this information can be combined with Eqs. (4) and (5) to determine the work, $W_{\text{NC}}^{\text{collision}}$, done by non-conservative forces during the collision, and the work, $W_{\text{NC}}^{\text{traveling}}$, done by other non-conservative forces while the cart travels along the track.

Initial set-up

✎ Weigh and record the mass of the cart.

1. Elevate the side of the track opposite the spring about 8 or 10 centimeters so that the cart can roll toward the spring bumper.
   ☞ *Your track is two meters long, but you will only use the 60 centimeters of it closest to the spring.*

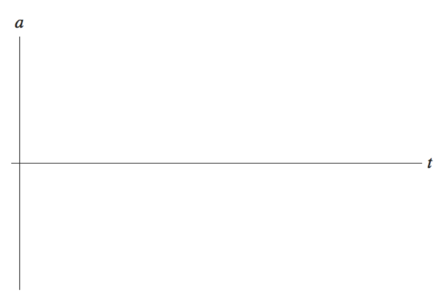
2. Open Movie Maker and prepare to record video from the webcam.

3. Position the webcam so that you can fully view the 60 centimeters of the track closest to the spring.

4. Prepare the smartphone so that you can record accelerometer data as it rolls down the track. Then, place the smartphone on the cart.
   ☞ *It is extremely important that you have the data recording rate in your app set to the fastest setting!*
   ☞ *Practice the release of the cart multiple times before you begin collecting data.*

Hypothesis

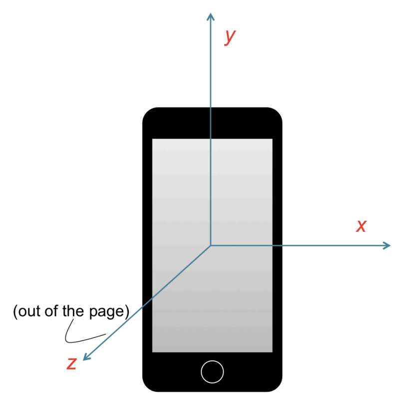
✎ On the axes provided below, sketch your prediction of what the accelerometer graph of interest will look like during the period of time that *the cart makes contact with the spring.*
☞ *You may find it helpful to keep in mind that $F = ma$. What kind of force will the cart experience?*



Take a photo of your sketch and upload it to WebAssign.

CHECKPOINT 2: Ask your TA to check your graph before proceeding.

✎ Which axis' acceleration are you interested in?



Data Acquisition and Analysis

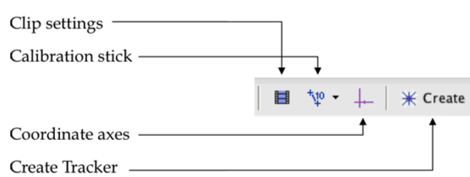
5. Select a starting point about 60 centimeters from the spring. ✎ Record this distance.

6. Measure the vertical distance from the floor to the top edge of the track at the starting position.
   ✎ Record this as the starting position height.

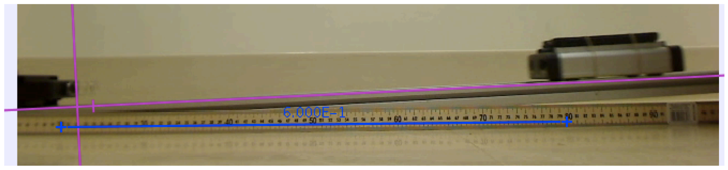
7. Begin recording video from the webcam and accelerometer data on the smartphone. Release the cart.
   ☞ *Be careful not to push the cart up or down the track!*
   ☞ *Push the record button for both the video and the smartphone,* ***wait a moment,*** *then release the cart.*

8. Once the cart has returned back up the track, stop recording on both the computer and the smartphone. Open the webcam video in Tracker and open the accelerometer data from your smartphone in Excel.

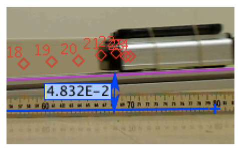
9. In Tracker, set the appropriate clip settings and set the calibration stick distance.



10. Orient the coordinate axes, and be sure to rotate the horizontal axis so that it is parallel to the track! Then, shift + click to track the position of the cart as it moves down the track.



11. Use Tracker to determine the *maximum* height at which the cart temporarily stops after it has bounced back up the spring. (That is, you want to obtain h_4.)
☞ *You can do this by navigating to the appropriate frame where the cart returns to a maximum height and clicking the "calibration stick" icon. Then choose "new → calibration tape" from the pop-up menu that appears. Move your "tape" so that you can effectively measure the starting height, as shown in the screenshot below.*



12. Use Tracker's plots of velocity versus time to find the initial and final speeds of the cart, immediately before and after hitting the spring. (That is, you want to determine v_2 and v_3.)

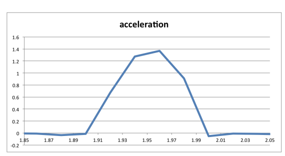
CHECKPOINT 1: Ask your TA to check your data before proceeding.

Calculations

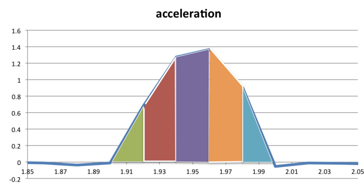
1. Graph this axis' acceleration versus time (or 'recordtime') in Microsoft Excel.
2. Knowing that $F = ma$, we can say that

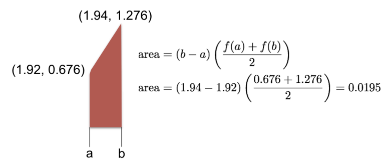
$$\begin{aligned}\text{Impuse} &= \int_{t_i}^{t_f} F\,dt \\ &= \int_{t_i}^{t_f} ma\,dt \\ &= m\int_{t_i}^{t_f} a\,dt \qquad \text{because mass is constant with time.}\end{aligned}$$

3. Estimate $\int a\,dt$ from the area under the curve by using the trapezoidal rule, as illustrated below. Your acceleration graph may look something like this:



You may break up the graph into several trapezoids, and find the area of each trapezoid individually. (The calculation for the area of one trapezoid is shown below.) You can then add up all of the areas of all of the trapezoids to find the total area under the curve.





The sum of all of the trapezoids' areas gives you the area under the a versus t curve, or $\int a\, dt$. Then, find $\int F\, dt = m \int a\, dt$.

4. Calculate the change in *momentum* from the values of v_2 and v_3 that you obtained from Tracker.

5. Compare your calculation of $\int F\, dt$ to Δp by computing the percent difference between the two. Recall that the percent difference between two quantitates, A and B is simply the difference in the two divided by the average:

$$\%\ \text{difference} = \frac{A - B}{\frac{1}{2}(A + B)}.$$

CHECKPOINT 3: Ask your TA to check your impulse calculations.

5. Use the initial and final speeds recorded by Tracker to calculate the energy loss during the collision.

6. Use the starting and stopping height to compute the total energy loss for the entire trip.

7. Compute and record the average values of $\Delta E_{\text{collision}}$ and ΔE_{total}.

8. Use these values to determine the percentage of the total energy loss that occurred during the collision.

9. Use the average energy losses to determine the amount of work done by non-conservative forces during the collision as well as the amount of work done by other non-conservative forces during the rest of the cart's trip.

CHECKPOINT 4: Ask your TA to check your energy loss calculations.

Lab 6, WebAssign

MT Lab 6 - Impulse, Momentum, & Energy v2 (5466113)

Current Score: 0/100 **Due:** Fri Oct 17 2014 12:15 PM EDT

Question	1	2	3	4	5	Total
Points	0/3	0/30	0/22	0/22	0/23	0/100

Instructions

Instructions

VPython Instructions

1. 0/3 points MT Lab 1 Group Roles [2694084]

Group Roles

Before you start the lab, identify who on your team will assume roles shown below. If necessary, read the descriptions of Group Roles for Labs.

Lab Manager ✗ Manager's Name

Recorder ✗ Recorder's Name

Skeptic ✗ Skeptic's name

2. 0/30 points MT Lab 6- Data [2743225]

Use the exact values you enter to make later calculations. Include units in your answers. More information.

Experimental Setup – Data

What is the mass of the cart?

✗ 0.5 kg

Data Acquisition

What is the starting position of the cart?

✗ 0.75 m

What is the height of the starting position of the cart?

✗ 0.075 m

What is the stopping position of the cart?

✗ 0.55 m

What is the height at the stopping position of the cart?

✗ 0.065 m

What is the speed before the collision?

✗ 0.5 m/s

What is the speed after the collision?

✗ 0.48 m/s

Procedure A: Impulse

Upload your sketch of your prediction for the accelerometer data here.

Choose File No file chosen

Key: accelerometer file upload

Calculate the force and the magnitude of the change in momentum for the time interval and enter the values below. (Do not include units in your answers.)

Using the trapezoidal method, what is the area under the force versus time curve?

0.48 N · s

Using Tracker, what was the change in momentum?

0.49 kg · m/s

What is the percent difference between the average area and the average value in the change in momentum? (Percent differences should not be rounded to one significant figure.) HINT

2.06 %

Should these two determinations be the same?

- Yes
- No

Procedure B: Energy

Answer the questions below. (Do not include units in your answers.)

What is $\Delta E_{\text{collision}}$?

-0.0049 J

What is ΔE_{total}?

-0.0491 J

What percentage of the energy loss occurred during collision?

9.99 %

Where did the most energy loss occur? (Assume energy lost during travel and energy lost during the collision are approximately equal if within 5% of each other.)

- during the cart's travel down and up the track
- during the collision
- The energy lost during the cart's travel down and up the track was approximately equal to the energy lost during the collision.

What is the amount of work done by non-conservative forces during collision?

$W_{\text{NC, collision}}$ = ________ -0.0049 J

What is the amount of work done by non-conservative forces while the cart is traveling?

$W_{\text{NC, traveling}}$ = ________ -0.0442 J

Where does the majority of the energy that is lost during the collision go? (Select all that apply.)

- friction between the wheels and the track
- in compressing the spring
- heat in the bearings

Where does the majority of the energy that is lost while the cart travels along the track go? (Select all that apply.)

- [ ] friction between the wheels and the track
- [ ] in compressing the spring
- [ ] heat in the bearings

Analysis

Is the momentum of the cart conserved in this experiment?

- Yes
- No
- cannot be determined

Would it be conserved if the speed of the cart before the collision were exactly equal to the speed of the cart after the collision?

- Yes
- No
- cannot be determined

Explain your answer to the second part in terms of physics concepts.

Key: Momentum is a vector. Two momentum vectors are equal only if their magnitudes are equal and their directions are the same. So no, the momentum of the cart is not conserved in this experiment because the initial and final momenta are different in both magnitude and direction. The momentum would not be conserved even if the initial and final speeds were the same. This is because, even though the magnitudes of the initial and final momenta would be equal, they would still be in opposite directions. Of course, the momentum of the total system of both the cart and the spring-bumper is conserved if there are no net external forces. We assume that the gravitational force is small compared to the spring force during the time the collision occurs.

3. 0/22 points NCSUCalcPhysMechL3 6.VP.001. [2726633]

The following questions concern the spacecraft interacting with the Earth and the Moon.

(a) What was the initial speed required to get the spacecraft to do a figure-8?

3290 m/s

(b) When the initial speed of the spacecraft is 3.27e3 m/s, which of the following statements are true? (Select all that apply.)

- [ ] The direction of the spacecraft's momentum is changing at every instant.
- [ ] At every instant, the net gravitational force on the spacecraft is the superposition of the gravitational force due to the Moon and the gravitational force due to the Earth.
- [ ] At the instant when the spacecraft begins to retrace its path, the magnitude of the net force acting on the spacecraft is zero.
- [ ] The gravitational force on the spacecraft due to the Moon is always perpendicular to the spacecraft's momentum.
- [ ] At the instant when the spacecraft begins to retrace its path, its speed is zero.
- [ ] The magnitude of the spacecraft's momentum is constant.
- [ ] At every instant, the momentum of the spacecraft is tangent to the spacecraft's trajectory.

4. 0/22 points NCSUCalcPhysMechL3 6.VP.002. [2726628]

Consider the energy graphs for the system of the spacecraft, the Earth, and the Moon. Set the initial conditions of your program so that the spacecraft makes a figure-8 orbit around the Earth. Examine plots of total K, U, and $K + U$ vs. time in your program for this case. Which of the following are true? (Select all that apply.)

- [ ] Total K reaches zero at some point in the orbit.
- [ ] $K + U$ is a positive constant.
- [ ] U decreases when the spacecraft and the Earth get closer to each other.
- [ ] U is always negative.
- [ ] Total K is negative when the spacecraft and the Earth are farthest from each other.
- [ ] U is a maximum when the total K is a minimum.

Solution or Explanation

When the spacecraft and the Earth are at their closest distance to each other, the total K is a maximum.

5. 0/23 points NCSUCalcPhysMechL3 6.VP.003. [2726630]

Turn in your VPython program below.

- Before turning in your program, compare your running program to that of another group, and then show your running program to your TA.
- Make sure you turn in a working version of your program since you will not receive credit if the program doesn't run. It's a good idea to run your program one last time just before turning it in.
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Upload your program. (Submit a file with a maximum size of 1 MB. The file name should have the extension ".py". For example, your file name could be "spring-mass.py".)

Choose File No file chosen

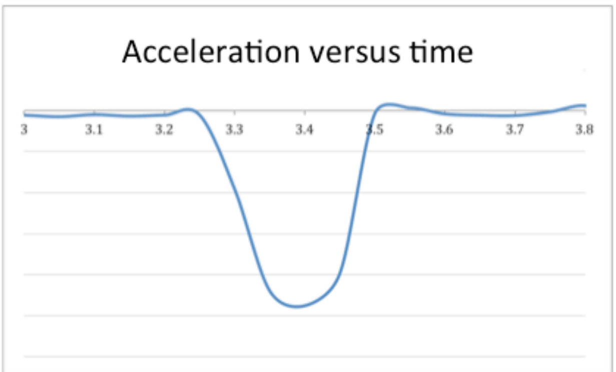
Key: Answers may vary.

Assignment Details

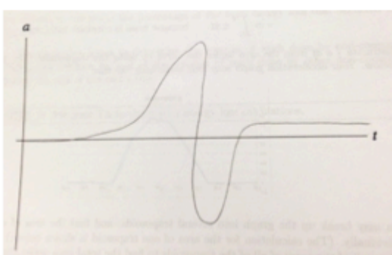
Lab 6, Student Responses to MyTech Questions

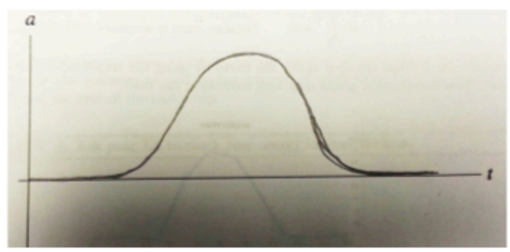
✎ On the axes provided below, sketch your prediction of what the accelerometer graph of interest will look like during the period of time that *the cart makes contact with the spring.*
☞ *You may find it helpful to keep in mind that $F = ma$. What kind of force will the cart experience?*

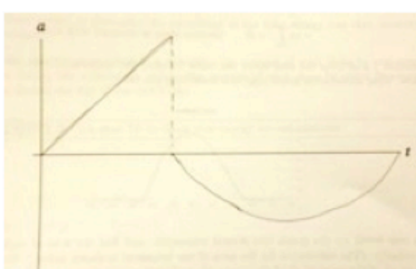
Key

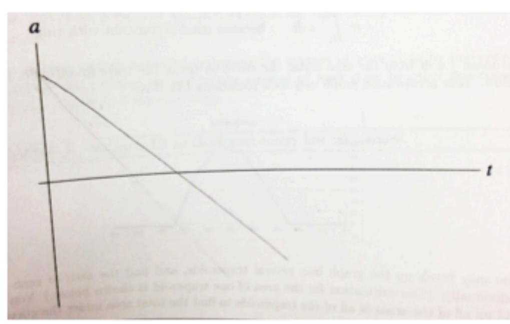


Fall 2013 Responses

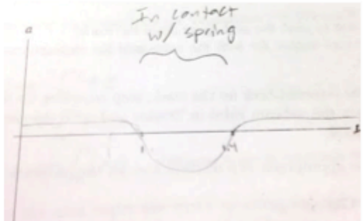


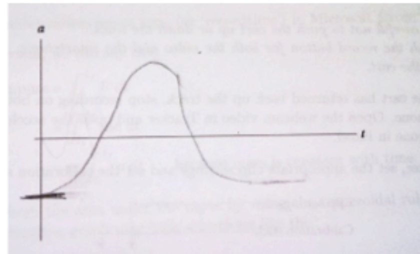


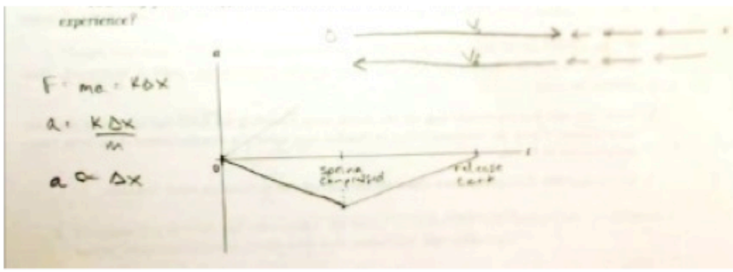




Spring 2014 Responses

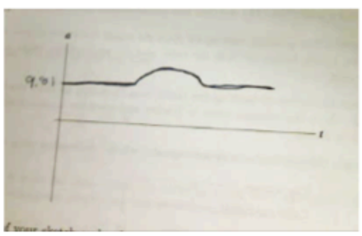


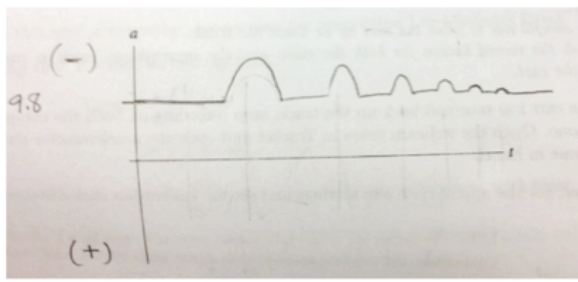


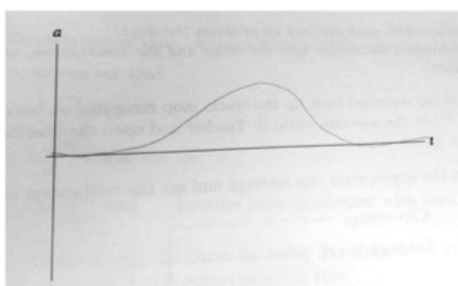


2 groups submitted this same image.

Fall 2014 Responses







Lab 7, Procedure

Spring Oscillations

You will be using two different principles to determine the stiffness of a spring, and comparing the outcomes of the two methods. One method involves measuring the stretch s resulting from an applied force and using Hooke's Law,

$$\left|\vec{F}_{spring}\right| = ks$$

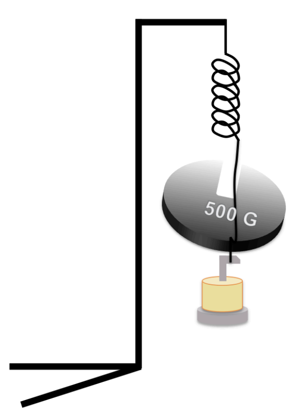
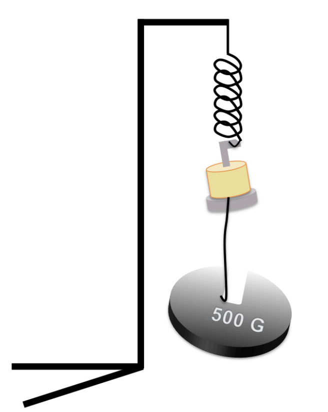
The second method involves measuring the oscillation period of a mass hanging on the spring and using the relationship among mass m, spring constant k, and oscillation period T,

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Note that the period of a spring pendulum is only reliant on m and k.
For more details about these equations, see the handout on concepts.

Using Hooke's Law

- Record the spring color in WebAssign or the rest of your questions will be marked incorrect.
- Consult the chart below to determine what mass values to use with your spring. Remember to account for the mass hanger.
- Hang mass m_1 from the hanger, record the total length of the spring (not including the hanger or masses), repeat with mass m_2, and record the values in Data Table 1.

YES	NO
	
When using masses over 0.5 kg, be sure to hang the small mass hanger from the large mass to avoid breaking the small plastic mass hanger.	

- Calculate the spring constant. See the concepts handout for more details about this calculation.

Mass Values		
Spring Color	Mass 1 (g)	Mass 2 (g)
Red	250	500
Blue	300	600
Yellow	350	700
White	450	900
Green	550	1100

Using a graph of T^2 vs m

- Suspend the m_1 for your spring color on the spring. Give the mass a small displacement (3-4 cm) and let it start bouncing. Try to ensure it moves vertically without side-to-side swinging.
- Using your smartphone's stopwatch function, measure the time for 10 complete oscillations and record it in Data Table 2. Taking 10 oscillations will give more accurate results with less error due to measurement.
- Perform 3 total trials, averaging the times together, to increase accuracy. Finally, determine the period of a single oscillation from this average time.
- Repeat the measurements three more times, doing three trials of each. Use values between m_1 and m_2 for the 2nd and 3rd measurements, then use m_2 for the last set.
- Using linear regression and the equations of simple harmonic motion, determine the value of the spring constant.

Simple Pendulum

Important notes: Use only small displacement angles when swinging the pendulum (less than 20° from vertical) and don't use a pendulum length less than 50 cm.

Using a graph of T^2 vs L

For a simple pendulum (a point mass suspended on a light string), the relationship among period, pendulum length L, and the acceleration due to gravity is very similar to the mass-spring equation above. If the pendulum is moving only through small angular distances, the relation is

$$T = 2\pi\sqrt{\frac{L}{g}}$$

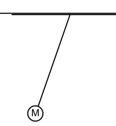
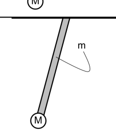
Note that the period of a simple pendulum is only reliant on L.

- Construct a simple pendulum by hanging the metal bob by a string from the horizontal bar of the stand assembly.
- Record the length of the pendulum. Note that the length should be the distance from the pivot point to the *center of mass* of the pendulum bob.
- Using the same methods as you used with the mass and spring, determine the amount of time for ten oscillations with multiple trials averaged together, and then calculate the experimental value of the period.
- Change the length of the pendulum by at least 20 cm and follow all the steps above. Do four total measurements, varying the length by at least 20 cm.
- Using linear regression and the equations of simple harmonic motion, determine the experimental value of the acceleration due to gravity.

Physical Pendulum

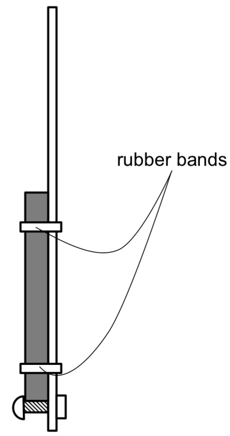
Determining Period from Accelerometer Graphs

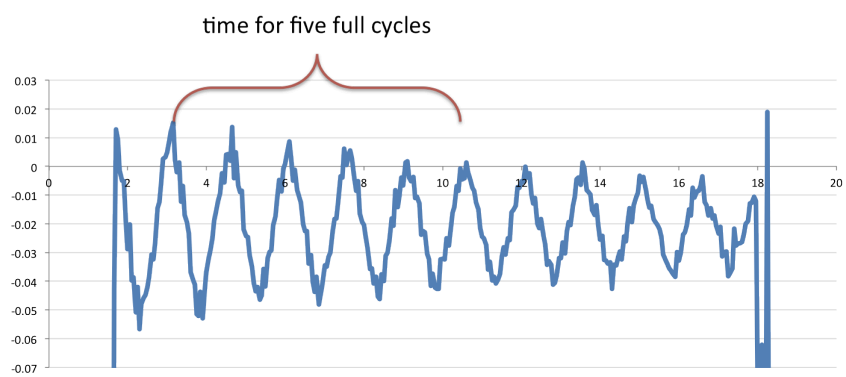
For physical pendulums such as the one we are using in this lab, we must acknowledge that mass is distributed along the length of the rod and thus, the period is affected by some multiplicative factor, F.

simple pendulum		$T = 2\pi\sqrt{\frac{L}{g}}$
physical pendulum		$T = 2\pi F\sqrt{\frac{L}{g}}$

It has previously been determined that, for our experimental apparatus, $F = 0.88$ (although you can see more details in the document "Physical Pendulum Concepts", if you are interested).

- Remove the spring holder from the rod and *screw on* the physical pendulum apparatus.
- Attach your smartphone to the base of the pendulum rod, as shown in the side-view diagram. You can rest the phone on the screw at the bottom of the rod.
- Record the length, L, from the top of the rod to the bottom of the rod.
- Record accelerometer data while the device is experiencing periodic motion. (See "how to record accelerometer data" for more information.)
- Determine the period from the accelerometer graphs by measuring the time that it takes to complete five cycles and then dividing by five.





- Record your data in the space below:

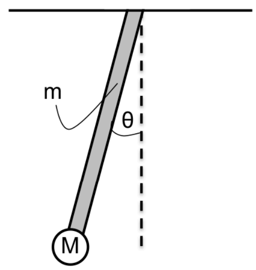
  $L =$ ________________, $F = 0.88$, $T =$ ________________.

- Calculate your experimental value of g.

Lab 7, Concepts

The Period of a Physical Pendulum

Consider a physical pendulum, whose mass is distributed along the length of the rod, L, (where m is the mass of the rod) as well as clustered at the bottom of the pendulum (where M is the mass of the pendulum bob).



Then you can compute the net gravitational torque on the system at an arbitrarily small angle θ:

$$\tau = -\left(\frac{L}{2}mg + L_{cm}Mg\right)\sin\theta,$$

where L is the full length of the pendulum, and L_{cm} is the distance from the axle to the center of mass of the smartphone.
Note that there is a negative sign because the torque opposes the angular displacement from equilibrium.
Knowing that $\tau = I\alpha = I\frac{d^2\theta}{dt^2}$ and that θ is small, we can now say

$$\begin{aligned}
\tau &= -\left(\frac{L}{2}mg + L_{cm}Mg\right)\sin\theta \\
I\frac{d^2\theta}{dt^2} &= -\left(\frac{L}{2}mg + L_{cm}Mg\right)\sin\theta \\
0 &= I\frac{d^2\theta}{dt^2} + \left(\frac{L}{2}mg + L_{cm}Mg\right)\sin\theta \\
0 &= \frac{d^2\theta}{dt^2} + \underbrace{\frac{\left(\frac{L}{2}mg + L_{cm}Mg\right)}{I}}_{=\omega^2}\theta
\end{aligned}$$

where

$$I = \frac{1}{12}mL^2 + ML_{cm}^2.$$

We can now obtain the angular frequency:

$$\omega^2 = \frac{4\pi^2}{T^2} = \frac{\left(\frac{L}{2}mg + L_{cm}Mg\right)}{I}.$$

Solving for the square of the period, T^2, we see

$$\begin{aligned}
T^2 &= \frac{4\pi^2 I}{\frac{L}{2}mg + L_{cm}Mg} \\
&= 4\pi^2 \left(\frac{\frac{1}{12}mL^2 + ML_{cm}^2}{\frac{L}{2}mg + L_{cm}Mg} \right) \\
&= \frac{4\pi^2}{Lg} \left(\frac{m\left(\frac{L^2}{12}\right) + M(fL)^2}{\frac{m}{2} + fM} \right) \qquad \text{where } L_{cm} := fL \\
&= \frac{4\pi^2 L}{g} \left(\frac{\frac{m}{12} + f^2 M}{\frac{m}{2} + fM} \right) \\
T &= 2\pi\sqrt{\frac{L}{g}} \underbrace{\sqrt{\frac{\frac{m}{12} + f^2 M}{\frac{m}{2} + fM}}}_{:=F}.
\end{aligned}$$

Thus we can write the period of a physical pendulum as

$$\boxed{T = 2\pi\sqrt{\frac{L}{g}}F}$$

where F is some multiplicative factor that depends on the mass of the rod, m, and the mass of the bob, M:

$$\boxed{F = \sqrt{\frac{\frac{m}{12} + f^2 M}{\frac{m}{2} + fM}}.}$$

Using the masses of the rods (without the axles at the top), you can find the values of F experimentally for each of the lengths:

L (m)	F
0.7165	0.886
0.6170	0.872
0.5090	0.873
0.4155	0.882

So we use the average value of $F = 0.878$ in the experiment.

Lab 7, WebAssign

MT Lab 7 - Simple Harmonic Motion v2 (5492585)

Current Score: 0/100 **Due:** Fri Oct 24 2014 12:15 PM EDT

Question	1	2	3	4	5	**Total**
Points	0/3	0/24	0/24	0/24	0/25	**0/100**

Instructions
Procedure
Reminder on How to Record Accelerometer Data
Spring Pendulum and Simple Pendulum Concepts
Physical Pendulum Concepts
Linear Regression Hints

1. 0/3 points MT Lab 1 Group Roles [2694084]

Group Roles

Before you start the lab, identify who on your team will assume roles shown below. If necessary, read the descriptions of Group Roles for Labs.

Lab Manager ✗ Manager's Name
Recorder ✗ Recorder's Name
Skeptic ✗ Skeptic's name

2. 0/24 points NCSUCalcPhysMechL3 7.IL.001. [2735336]

Use the exact values you enter to make later calculations. Include units in your answers. More information.

Spring Oscillations: Using Hooke's Law

What color is your spring?
---Select--- ✗

You will be determining the spring constant from Hooke's Law. Complete the table below. **Make sure to read the instructions.**
Table 1

Mass (kg)	Gravitational Force (N)	Length (m)
✗ 0.25	✗ 2.45	✗ 0.2
✗ 0.5	✗ 4.91	✗ 0.3

What is the spring constant of your spring, calculated with Hooke's Law? *(Remember that you'll need to use the difference between the two measurements because you don't know the relaxed length. See the instructions for details.)*
✗ 24.5 N/m

The actual spring constant is written on the box for the springs. What is the percent error of your measurement as compared to the actual value?
✗ 1.9 %

Spring Oscillations: Using a Graph of T^2 vs. m

You will be determining the spring constant from T^2 vs. m graph. Complete the table below. **Make sure to read the instructions.**
Table 2

Total Vibrating Mass (kg)	Time for 10 Vibrations (s)				Observed Period T (s)
	1	2	3	Average	
0.25	6.28	6.28	6.28	6.28	0.628
0.375	7.7	7.7	7.7	7.7	0.77
0.375	7.7	7.7	7.7	7.7	0.77
0.5	8.89	8.89	8.89	8.89	0.889

What is the slope of the plot of T^2 versus m?

1.58 s^2/kg

What is the spring constant k as determined from the slope?

25 kg/s^2

What is the percent difference between the two values of the spring constant?

1.92 %

What is the percent error of your measurement as compared to the actual value?

0 %

Additional Materials

Simple Harmonic Motion - Concepts

Simple Harmonic Motion - Procedure

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3. 0/24 points NCSUCalcPhysMechL3 7.IL.002.K. [2735338]

Use the exact values you enter to make later calculations.

Simple Pendulum: Using a Graph of T^2 vs. L

You will be determining the acceleration due to gravity from a T^2 vs. L graph. Complete the table below. **Make sure to read the instructions.**

Table 3

Pendulum Length L (m)	Time for 10 Oscillations (s)				Observed Period T (s)
	1	2	3	Average	
0.6	15.5	15.5	15.5	15.5	1.55
0.8	17.9	17.9	17.9	17.9	1.79
1	20.1	20.1	20.1	20.1	2.01
1.2	22	22	22	22	2.2

What is the slope of the plot of T^2 versus L?

4.02 s^2/m

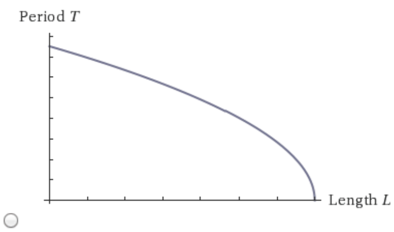
What is the acceleration due to gravity g as determined from the slope?

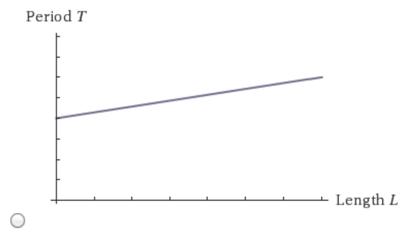
9.81 m/s^2

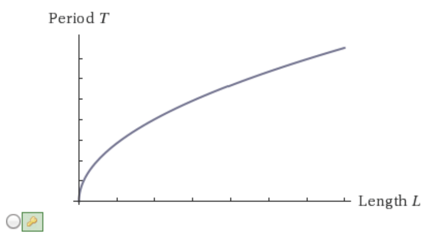
What is the percent error of your measurement as compared to the actual value?

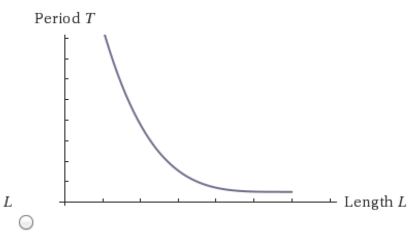
0 %

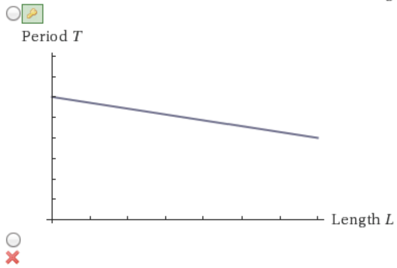
Look at the values of L and $T_{observed}$ in Table 3. Which of the following graphs correctly represents the relationship between T versus L?











Additional Materials

Simple Harmonic Motion - Concepts
Simple Harmonic Motion - Procedure - Alternate Lab

4. 0/24 points MT Physical Pendulum [2745070]

What is the length of your physical pendulum rod?

0.617 m

What is the period of the physical pendulum, as determined by the accelerometer data?

1.375 s

Calculate your experimental value of *g* as determined by the equation for the period of a physical pendulum. *Be sure to include the corrective factor* F *in your calculation.*

9.9765235285157 m/s^2

5. 0/25 points NCSUCalcPhysMechL3 7.IL.003. [2735337]

Analysis

Consider the measurement of the spring constant made by measuring the period of oscillation. In this lab, we made an assumption about lack of air resistance. If air resistance were a significant factor to the mass's motion, would ignoring its effect (as we did in the lab) cause a calculated value for the spring constant that is too high or too low? Justify your answer.

Key: Air resistance would slow down an oscillating mass or bob, thus increasing the period. A larger period implies a smaller value for k. Thus, the calculated k would be smaller than the actual value, since without air resistance we would have measured a smaller T value and correspondingly larger k.

Which method was more accurate for the determination of k? Why do you think this method yielded better results, and what might have contributed to discrepancies between the two methods? (Give specific contributing factors, not vague responses like "human error" or "measurement uncertainty.")

Key: Answers may vary, as long as the response is a reasonable assessment of possible error sources and is consistent with results.

Of your oscillation measurements, which was more accurate, k or g? What might have contributed to any errors here? How might the measurements be improved?

Key: Answers may vary, as long as the response is a reasonable assessment of possible error sources and is consistent with results.

Additional Materials

Simple Harmonic Motion - Concepts
Simple Harmonic Motion - Procedure

Assignment Details

Lab 8, Procedure

In this experiment you will roll a ball down a ramp and off the table, measuring horizontal and vertical distances associated with the motion in order to determine the speed of the ball at the time it leaves the table. You will use three different methods for this experiment:

1. Kinematics, treating the ball as a point mass in free fall
2. Energy, looking at conservation of the ball's energy
3. Tracker, analyzing video of the ball's motion

These methods are discussed in more detail below.

Kinematics

The first method will apply the principles of uniformly accelerated motion to treat the ball as a projectile. Measuring d and h_2 as illustrated in Figure 1 will be enough to calculate the velocity of the ball at the time it leaves the table.

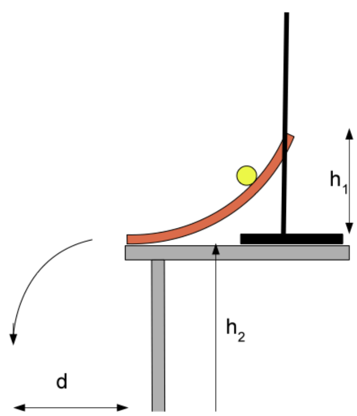


Figure 1: Sphere rolling down a ramp

As a reminder, the uniformly accelerated motion equations are reproduced below. For more details on this method, refer to the concepts handout at the top of the assignment page.

$$v_x = v_{x,0} + a_x t \qquad v_y = v_{y,0} + a_y t$$

$$x = x_0 + v_{x,0} t + \frac{1}{2} a_x t^2 \qquad y = y_0 + v_{y,0} t + \frac{1}{2} a_y t^2$$

$$v_x{}^2 = v_{x,0}{}^2 + 2a_x (x - x_0) \qquad v_y{}^2 = v_{y,0}{}^2 + 2a_y (y - y_0)$$

Arrange the track and stand as illustrated in Figures 1 and 2. Important notes:

- Make sure the bottom part of the track is flat and ends at the edge of the table
- Make sure the top part of the track is angled, not vertical
- Make the track as stable as possible using the provided clamps, tape, and anything else that seems handy

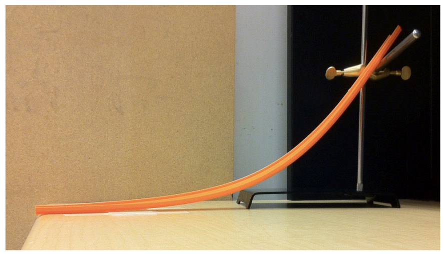


Figure 2

Hold the ball steady at a point on the track and record the vertical distance from the table to the ball. *(Hint: Should you measure to the top, middle, or bottom of the ball?)* This will be h_1 as illustrated in Figure 1.

Release the ball and record where it lands. One method of doing this is to use the supplied carbon paper. If you use carbon paper, put a blank piece of paper down where the ball will land, then the carbon paper black-side down on it. The ball's impact will make a mark on the paper. If you use the paper, make sure to hold or tape it still so it doesn't slide when the ball impacts.

The horizontal distance from the edge of the table/ramp to the impact point will be d as illustrated in Figure 1. The vertical distance from the table top to the floor will be h_2.

In order to improve the accuracy of the data, you will perform this measurement two more times using the same starting height (that is, the same h_1), finding the average value for d over the trials. Then for further accuracy, you will repeat the experiment with different starting locations, performing three trials for each different h_1.
Finally, use the kinematics equations and the collected data to determine the velocity of the ball at the instant it left the ramp.

Energy

Next, you will calculate the speed of the ball as it leaves the track again, this time using conservation of energy methods. During the ball's roll down the ramp we will assume that it is rolling without slipping. This would mean that friction, while present, is not doing any work. If we also ignore the very small contribution due to air resistance, the conclusion is that the ball has no non-conservative force doing work on it and thus its mechanical energy is conserved.

As a reminder, here are the expressions for various types of mechanical energy:

$$K_{\text{trans}} = \frac{1}{2}mv^2 \qquad K_{\text{rot}} = \frac{1}{2}I\omega^2 \qquad U_g = mgy$$

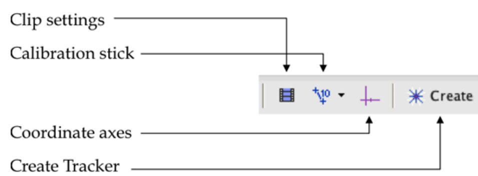
Note that for a solid sphere, $I = \frac{2}{5}MR^2$.

Using the data you collected in the Kinematics section, calculate the velocity at the bottom of the ramp for each starting height. Use the starting position (at the top of h_1) and the end of the ramp as your initial and final points. Should these calculations yield the same results as the kinematics calculations?

Tracker

Finally, you will calculate the speed of the ball as it leaves the track again, this time using Tracker to determine the speed of the ball as it leaves the track.

Repeat the experiment by using one of the values of h_1 from the previous section of the experiment as the starting position. (Do not reposition the top of the track.) Position the camera so that the track and meterstick are in the field of view. Record a video of the motion, and then import it into Tracker for analysis. Use the following buttons to track the ball's motion down the track. (In clip settings, make sure that you only analyze every other frame by choosing "2" as the step size.)



After you've finished tracking the motion, plot v (*of which axis?*) versus t to determine the velocity at the bottom of the track. Save a screenshot of the plot and upload it to WebAssign. (You can save a screenshot by right-clicking on the plot area, choosing "Snapshot..." and then selecting "File", "Save as .png".)

Conclusion

Your answers to these questions will be entered into WebAssign.

Think about the simplifications and assumptions that were made in order to apply the two different calculation methods. For the various factors that were ignored or overlooked (e.g. air resistance), would their contribution tend to make your calculations be too high or too low compared to the true values? *(Note that it is certainly possible that some factors would tend to make the calculation higher and others make it lower.)*

Taking in mind the factors mentioned above, do you feel that their combination would overall tend to make your calculated values too large, too small, or about the same?

Which method do you believe had more potential sources of error or oversimplification? Why?

Lab 8, WebAssign

MT Lab 8 - Cons of Mech Energy v2 (5535790)

Current Score: 0/100 **Due:** Fri Oct 31 2014 12:15 PM EDT

Question	1	2	3	Total
Points	0/3	0/48.5	0/48.5	0/100

Instructions
Procedure

1. 0/3 points MT Lab 1 Group Roles [2694084]

Group Roles

Before you start the lab, identify who on your team will assume roles shown below. If necessary, read the descriptions of Group Roles for Labs.

Lab Manager		Manager's Name
Recorder		Recorder's Name
Skeptic		Skeptic's name

2. 0/48.5 points MT Lab 8 Data [2747925]

Use the exact values you enter to make later calculations.

What is your vertical distance from the table to the flat part of the ramp?

h_2 = 60 cm

Kinematics

Complete the data table below. h_1 is the height through which the sphere descends while on the ramp.

Table 1

Position	h_1 (cm)	Horizontal Distance d (cm)				v_{kine} (cm/s)
		Trial 1	Trial 2	Trial 3	Average	
1	25	65.5	65.5	65.5	65.5	187
2	25	65.5	65.5	65.5	65.5	187
3	25	65.5	65.5	65.5	65.5	187
4	25	65.5	65.5	65.5	65.5	187
5	25	65.5	65.5	65.5	65.5	187

Energy

Complete the data table below using the same values of h_1 as in Table 1.

Table 2

Position	h_1 (cm)	v_{energy} (cm/s)
1	25	187

2	____ ✖	25	____ ✖	187
3	____ ✖	25	____ ✖	187
4	____ ✖	25	____ ✖	187
5	____ ✖	25	____ ✖	187

Tracker

Choose one of your values for h_1 from the previous parts, then repeat the experiment. This time, recording it on video and analyzing it in Tracker.

What value of v_f did you obtain from the Tracker analysis?

✖ 187 cm/s

Upload a screenshot of the velocity plot.

Choose File No file chosen

Key: velocity file upload

Comparison

The following questions relate to the questions in the conclusion section of the lab instructions.

What are some of the sources of uncertainty in this lab that could have contributed to a discrepancy in the two data sets or to one or both of the calculations being too high or low? Specify which calculation method each source of uncertainty would contribute to, and whether it would tend to make the calculation too low or too high.

Key: Answers will vary: incorrect reading of v_{kine} values from the graph; not placing the center of the steel sphere at the appropriate height; not releasing the steel ball from the same location for all three trials; shift in the carbon paper during the course of the experiment leading to incorrect measurement of x; assumed that friction is negligible along the ramp, but this could have contributed to the discrepancy in the two data sets.

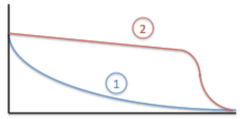
Considering all the sources of uncertainty you identified above, which method of calculation do you feel is likely to give a more accurate result? Consider how many sources of uncertainty each method might have and the magnitude of those uncertainties in your conclusion.

Key: Answers will vary. The velocity of the ball at the bottom of the ramp was determined using kinematics and the conservation of mechanical energy principle. The two values agree within the range of experimental uncertainties. This shows that mechanical energy is conserved as the ball rolls down an inclined ramp.

3. 0/48.5 points NCSUCalcPhysMechL3 8.IL.002.K. [2747048]

Questions

Consider a situation in which this experiment was redone using the two tracks in the figure labeled as tracks 1 (blue) and 2 (red). Assume the diagram is drawn to scale.



(a) If a ball were released from the top (left side) of tracks 1 and 2 simultaneously, which ball would reach the end of the track first? Why?

Key: The ball on track 1 reaches the end first, because it has its acceleration early and thus is moving at a higher speed through most of the motion.

(b) Compare the speed a ball would have at the end of track 1 vs. at the end of track 2. Explain your answer.

Key: Ignoring air resistance and assuming rolling without slipping, they should both have the same speed at the end of the track. Energy arguments should be the easiest way to justify.

(c) Air resistance is a velocity-dependent force; that is, it gets stronger as objects move more quickly through the air. With this in mind, what would change about the answer to part (b) if a lightweight wooden ball were used instead of a heavy steel ball? Why?

Key: A very lightweight ball would be significantly more affected by air resistance than a heavier one, and since air resistance is proportional to speed, the ball on track 1 would experience more drag and lose a larger proportion of its energy, ending up slower at the end than the ball on track 2.

Additional Materials

Conservation of Mechanical Energy - Concepts
Conservation of Mechanical Energy - Procedure - Alternate Lab

Assignment Details

Lab 9, Procedure

Angular Impulse and Angular Momentum Change

1 Purpose

In this lab you will use measurements to relate the angular impulse $\vec{\tau}_A \Delta t$ to a change in angular momentum $\Delta\vec{L}$.

2 Experimental Setup

Equipment: rotational apparatus, pulley, ruler, balance.

2.1 Equipment setup

The apparatus should be set up as in the figure below.

- On the bottom of the disk there is a set of grooves. Wind the string around the grooved disk with the smallest radius.
- Hang a mass (between 50 and 175 g) from the end of the string.
- Release the mass. The mass should fall, and the big disk should spin faster and faster.

1

- Place a smartphone (with a gyroscope) on the center of the turntable. Secure the position of the smartphone by wrapping a rubber band around the smartphone and threading it through the hook below the smartphone pictured above. Ask your TA if you need help.

2.2 Coordinate system

Using our usual coordinate system (x to the right, y up, z toward you), the big disk rotates in the $x-z$ plane, so its angular momentum will be in either the $+y$ or $-y$ direction. The torque exerted on the disk by the hanging weight will also be in the $+y$ or $-y$ direction.

2.3 Role of the pulley, and tension in the string

As long as friction with the axle and the moment of inertia of a pulley are small, little net torque is needed to make the pulley spin faster, so the tension in the string is nearly the same on both sides of the pulley. Therefore the force exerted by the string on the big disk (the "tension" force) is nearly the same as the force exerted by the string on the hanging mass.

When we release the mass, it starts from rest and then speeds up, so:

$$\frac{d\vec{p}_{\text{mass}}}{dt} = \vec{F}_T + \vec{F}_{\text{grav}} \neq \vec{0}$$

However, the rate of change of momentum of the mass is small (it speeds up, but not much), so we can safely make the approximation that

$$\left|\vec{F}_T\right| \approx \left|\vec{F}_{\text{grav}}\right| = mg$$

2.4 Torque

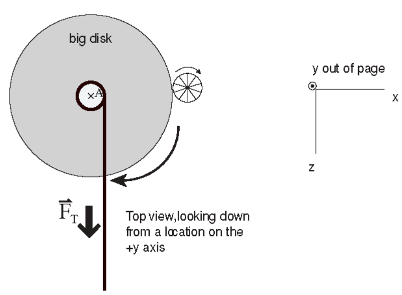
Remember that the definition of torque around a particular point A is:

$$\vec{\tau}_A = \vec{r}_A \times \vec{F}$$

We will take the center of the big disk to be location A. The y-component of torque, therefore, is

$$\tau_y = zF_x - xF_z$$

Imagine that the big gray disk is transparent, and you are standing on the $+y$ axis, looking down at the disk. The diagram below is drawn from that perspective, with $+x$ to the right, $+y$ out of the page toward you, and $+z$ down. The string is wrapped around the smallest grooved disk.



3 Initial Measurements

3.1 Moment of inertia of the large gray disk

- Measure the quantities that are necessary to calculate the moment of inertia of the gray disk, and record the data and calculation. For a disk of uniform density, $I = \frac{1}{2}M_{\text{disk}}R^2$. The disk is too heavy to weigh on our scale, but the disk's mass has previously been measured as $M_{\text{disk}} = 1.378$ kg.
- The smartphone also contributes to the moment of inertia of the system. You can assume the phone has no depth and can thus be treated as a rectangle with side lengths W and L so that $I = \frac{1}{12}M_{\text{phone}}(W^2 + L^2)$.
- Calculate the total moment of inertia of the disk-phone system.

3.2 Determining the change in angular speed of the disk

So far in this lab, we have only ever used the accelerometer to collect data on your smartphone, but recall that your smartphone can also record gyroscope (rotational) data.
Now, release the mass and **record the gyroscope data** as the disk-phone system rotates. Do not stop recording until the string has unwound completely, then rewound as the spinning disk pulls the mass back up.

Before moving on, ask yourself about which of the smartphone's axes are you most interested in. (Think about $\vec{\omega}$. What direction does it point as the smartphone spins?)

Plot ω versus t in Excel and save the resulting chart as a .png file (by right-clicking the chart). Then, upload the chart to WebAssign.

Your graph of ω vs. time should have two segments: one with positive slope and one with negative slope. You will need to determine which part of the graph corresponds to the speed increasing with the mass falling and which part corresponds to the speed decreasing with the mass rising. Note that the magnitudes of these slopes are different. You should have seen a similar effect in the Fan Cart lab earlier in the semester.

- From your chart, read two values of speed, measured across the same time interval (e.g. 2 seconds) from each segment of your graph and record these in the spreadsheet provided. This step is very important, so ask a TA for help if you are unsure.
- Calculate the change in angular speed of the disk over each of these two equal time intervals.

3.3 Determining torque

- Measure the quantities that are necessary to calculate the y-component of the torque exerted on the disk by the string, as the mass falls. Record that data and calculation.

Note that there is friction in the system; the torque due to the hanging mass is not the only contribution to the torque.

CHECKPOINT: Compare your data with another group to make sure it is reasonable.

4 Relating angular impulse $\vec{\tau}\Delta t$ to change in angular momentum

4.1 Change in angular momentum

- Use your results from Section 3 to calculate the change in the y-component of rotational angular momentum of the disk over each time interval (mass falling and mass rising). Record your calculations.

4.2 Angular Impulse

- Use your results from Section 3 to calculate the y-component of angular impulse due to the hanging mass over each time interval (mass falling and mass rising). *Don't forget to think about the direction.* Record your calculations.

4.3 Taking angular friction into account

When the mass is falling, the torque due to the mass acts to speed up the disk, but the frictional torque acts to slow it down. That is, if the torque due to the mass is in the $+y$ direction, the frictional torque is in the $-y$ direction. In terms of magnitudes:

$$\left|\Delta\vec{L}_{\text{falling}}\right| = (|\vec{\tau}_{\text{mass}}| - |\vec{\tau}_{\text{friction}}|)\Delta t$$

However, when the mass is rising, both the torque due to the mass and the torque due to friction are in the same direction, and act to slow down the disk. In terms of magnitudes:

$$\left|\Delta\vec{L}_{\text{rising}}\right| = (|\vec{\tau}_{\text{mass}}| + |\vec{\tau}_{\text{friction}}|)\Delta t$$

In other words, the friction decreases the magnitude of the net torque when the mass is falling, but it increases the magnitude of the net torque when the mass is rising.

Notice that by recording information for the mass falling and rising for equal Δt's, we can factor out the effect of friction. All we need to do is *average* the magnitude of angular impulse for the two cases! *Make sure you understand why before continuing.*

$$\frac{\left|\Delta\vec{L}_{\text{falling}}\right| + \left|\Delta\vec{L}_{\text{rising}}\right|}{2} = \frac{(|\vec{\tau}_{\text{mass}}| - |\vec{\tau}_{\text{friction}}|)\Delta t + (|\vec{\tau}_{\text{mass}}| + |\vec{\tau}_{\text{friction}}|)\Delta t}{2} = \frac{1}{2}\left(2|\tau_{\text{mass}}|\right) = |\tau_{\text{mass}}|$$

As long as Δt is the same for each interval!

- Calculate the average of the magnitudes of the changes in rotational angular momentum of the disk (taken over both time intervals).

  Caution! Make sure you average the *magnitudes* of the two $\Delta\vec{L}$'s.

CHECKPOINT: Compare your work with another group to make sure you agree.
Then answer the follow-up questions for this section in WebAssign.

Lab 9, WebAssign

MT Lab 9 - Angular Impulse & Momentum v2 (5567807)

Current Score: 0/100 **Due:** Fri Nov 7 2014 12:15 PM EST

Question	1	2	3	**Total**
Points	0/3	0/48.5	0/48.5	**0/100**

Instructions
Procedure
Excel Worksheet

---

1. 0/3 points MT Lab 1 Group Roles [2694084]

Group Roles

Before you start the lab, identify who on your team will assume roles shown below. If necessary, read the descriptions of Group Roles for Labs.

Lab Manager ✗ Manager's Name
Recorder ✗ Recorder's Name
Skeptic ✗ Skeptic's name

---

2. 0/48.5 points MT Lab 9 Data [2763146]

Answer the following questions as a group. Make your answers brief (one or two sentences) but clear.

Smartphone Gyroscope Data

Explain briefly how you determined the moment of inertia of the combined object (disk + smartphone).

Key: The moment of inertia of the combined object is the sum of the moments of inertia of the two objects.

Upload a screenshot of the angular velocity plot.

Choose File No file chosen

Key: omega file upload

Relating Angular Impulse to Change in Angular Momentum

For the mass **falling**, what direction is the *y*-component of the angular impulse *due only to friction*?

- the same direction as the component due to the hanging mass
- the opposite direction as the component due to the hanging mass
- It has no direction.

✗

For the mass **rising**, what direction is the *y*-component of the angular impulse *due only to friction*?

the same direction as the component due to the hanging mass

the opposite direction as the component due to the hanging mass

It has no direction.

How does the **magnitude** of the angular impulse *due only to friction* compare for the mass rising and for the mass falling?

The magnitude for the mass rising is larger than for the mass falling.

The magnitude for the mass rising is smaller than for the mass falling.

The magnitudes are equal.

For a given Δt, the **average** of $|\Delta L_{falling}|$ and $|\Delta L_{rising}|$ should be equal to which of the following?

$(|\tau_{mass}| - |\tau_{friction}|) \cdot \Delta t$

$|\tau_{mass}| \cdot \Delta t$

$(|\tau_{mass}| + |\tau_{friction}|) \cdot \Delta t$

$|\tau_{friction}| \cdot \Delta t$

Explain briefly.

Key: By averaging the change in angular momentum for both situations, the effect of the frictional torque for the mass falling is canceled by the frictional torque for the mass rising.

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3. 0/48.5 points NCSUCalcPhysMechL3 9.IL.002. [2748514]

Excel® Spreadsheet

Turn in the Excel® spreadsheet containing your data, calculations, and graphs here. The file name must end in ".xls". (Submit a file with a maximum size of 1 MB.)

Choose File No file chosen

Key: Answers may vary.

Supporting Materials

DataStudio Setup File Excel Spreadsheet

Additional Materials

Angular Impulse and Angular Momentum Change

Assignment Details

Speed Dependence of the Air Resistance Force

1 Purpose

When a moving object is in contact with objects in the surroundings, some of the object's kinetic energy can be dissipated, or transferred to the surroundings, which typically become hotter. You've encountered one type of dissipative force, sliding friction, which depends only on the objects and how they contact (coefficient of friction and normal force).

However, some resistive forces, like air resistance, depend on the speed of the object. In this lab, you will investigate how air resistance is related to speed. Figuring out this relationship is a little tougher than just looking up an equation, which may yield conflicting information. This is one of the most common models for air resistance:

$$|\vec{F}_{\text{air}}| = bv \tag{1}$$

where v is the object's speed through the air, and b is a drag coefficient that depends on air density and the object's size and shape.

However, other sources may use this model for drag instead:

$$|\vec{F}_{\text{air}}| = cv^2 \tag{2}$$

where c is again a drag coefficient.

Notice that one equation shows drag depending on the object's speed, while the other depends on speed squared. So even with the ability to look the equations up, it's sometimes still necessary to conduct an experiment to determine which equation is more applicable to a particular situation.

2 Experiment

Read all of Section 2 *before* starting the experiment!

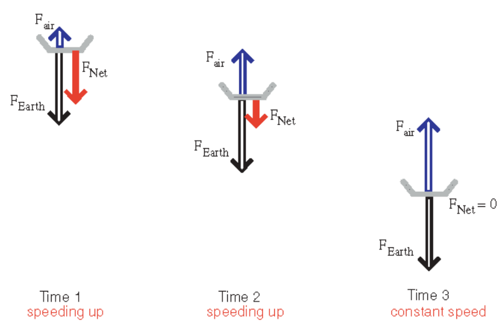
1. You will measure the speed of several moving objects of different mass but the same shape
   - The objects will be stacks of 1, 2, or 3 flat-bottomed coffee filters
2. You will determine the magnitude of $\vec{F}_{\text{air}}$, the air resistance force on each object
3. You will graph $\left|\vec{F}_{\text{air}}\right|$ versus v in Excel
4. You will fit the trend line to a power-law curve to find the value of the exponent n in the following equation

$$\left|\vec{F}_{\text{air}}\right| = \text{constant} * v^n$$

2.1 Terminal speed

- The speed of a falling object continually increases. How can we measure its speed?
  - Wait for its speed to become constant.
- Why will the speed become constant?
  - If the air resistance force increases as speed increases, eventually it will become equal in magnitude to the gravitational force on the object. At this point the object's speed stops changing. This speed is called *terminal speed*.

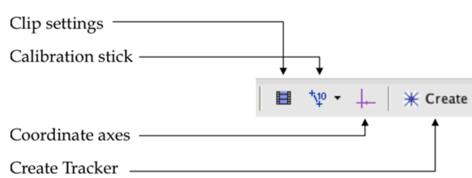
As the speed of the falling filter increases, $\left|\vec{F}_{\text{air}}\right|$ increases (Time 1 and Time 2) and the net force decreases, until $\left|\vec{F}_{\text{air}}\right| = \left|\vec{F}_{\text{Earth}}\right|$ (Time 3), and the net force is zero. Once the net force is zero, the filter falls at constant speed ("terminal speed").



2.2 Measuring terminal speed

Record all measurements and calculated values in a table in Excel.

- Drop the object (1, 2, or 3 filters) from a high location – near the ceiling in the lab, or from the top of stairs if available.
- Record the object's motion with a webcam and analyze the motion in Tracker. To make sure terminal speed has been reached, use only the video from the last meter of the object's fall.



- Track the object and plot v_y versus t. Use the plot to determine the object's terminal velocity.
- Repeat each measurement 2 times and average the times, to get better measurements
- Do this (2 measurements) for each object (6 measurements in all).

2.3 Determining the magnitude of $\left|\vec{F}_{\mathbf{air}}\right|$

- Once terminal speed is reached, $\left|\vec{F}_{\text{air}}\right| = \left|\vec{F}_{\text{Earth}}\right|$.

2.4 Finding the speed dependence

- Graph $\left|\vec{F}_{\text{air}}\right|$ versus v in Excel
- Add a trend line to the graph
- Fit the trend line to a power-law curve to find the value of the exponent n in the equation

$$\left|\vec{F}_{\text{air}}\right| = \text{constant} * v^n$$

3 Results

Turn in your Excel spreadsheet, including raw data, average speeds, and graph, to WebAssign. In your spreadsheet, write a 1 sentence conclusion – what did you find for the speed dependence of air resistance? You will also be asked to enter this value in WebAssign. (Note that if your value for the exponent is 6.979 this is indistinguishable from 7).

Lab 11, WebAssign

MT Lab 11 S14 Air Resistance (5602127)

Current Score: 0/100 **Due:** Fri Nov 21 2014 12:20 PM EST

Question	1	2	3	4	Total
Points	0/1	0/45	0/20	0/34	0/100

Instructions

Instructions **for the lab**

Excel file for recording data.

Handout on Percent Difference

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1. 0/1 points Group Roles [2434126]

Group Roles

Before you start the lab, identify who on your team will assume roles shown below. If necessary, read the descriptions of Groups Roles for Labs.

Lab Manager Key: student name

Recorder Key: student name

Skeptic Key: student name

---

2. 0/45 points Lab 11 Air Resistance [2551056]

Turn in your Excel spreadsheet, including graph, here: Choose File No file chosen

Key: excelfile

3. 0/20 points Lab 11 Follow Up MT [2894444]

In section 2.6, you compared the results you obtained using the first method (with the stopwatch) to the results you obtained using the second method (with Tracker). Were any of the values far off (>10% percent difference)?

- Yes
- No

Which method do you believe was more accurate?

- Stopwatch Method
- Tracker Method

Why? (List specific sources of error.)

Key: The Tracker method is likely more accurate as you don't need to rely on human reaction time, the way that you do in the stopwatch method.

4. 0/34 points Lab 11 Follow Up [2551438]

The full equation for the model of air resistance that uses v^2 is

$$F_{air} = \frac{1}{2} C_d \rho A v^2$$

where C_d is a drag coefficient, ρ is the density of air, and A is the cross-sectional area of the leading surface.

How does this equation match up with your data? Fill in the following table, using one set of terminal speed and force of air data from each filter type. You will need to determine the relevant area for the filter, and look up data for the density of air. The drag coefficient for a circular leading surface is approximately 0.47 (the ruffles make the shape more complicated, but this can be used as an approximation).

Filter size	# Filters	Terminal speed (m/s)	Force of Air (N)	C_d	ρ (kg/m^3)	Area (m^2)	Calculated drag force (N)	% difference between Force measurements
small	2	3	0.05	0.47	1.23	0.5	0	0
large	2	3	0.05	0.47	1.23	0.5	0	0

Judging by the percent difference between your measured force of air resistance and your calculated value using this method, how would you say this model fits your data? Is the fit better for the large or small filter? Why might that be? What sources might contribute to the difference you encountered?

Key: They should state which percent difference was closer, and give a reasonable analysis. They should at least address the question about why the fit may be better for the large or small filter, though so long as they say something about it that's sufficient. For sources of error, in addition to measurement error for the terminal speed, the measurement of the area is another potential source of error, as is the fact that the filter was treated as circular and the fringes were ignored.

Assignment Details

GRAPHING 1-D MOTION ADDENDUM

PHYSICS 241

Name: ___________________________ Lab partners:___________________________

Background

Use real-time accelerometer graphs ($a(t)$) to determine the $\pm x$, $\pm y$, $\pm z$ axes of the device.

Procedure

Download and open the SensorLog app. Make sure that the accelerometer mode is enabled.

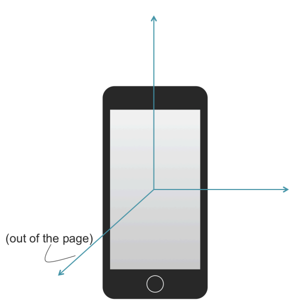
Move the device around and observe the three colored lines on the plot. Each line represents the acceleration experienced by the device along a certain axis. The instantaneous value is also displayed at the bottom of the plot. Note that red corresponds to the x-axis, green corresponds to the y-axis and blue to the z-axis.

Begin by orienting the smartphone upwards so that the bottom edge of the smartphone is making contact with the lab table. Keep the phone stationary and observe the accelerometer values.

What type of smartphone do you have? ____

To the nearest multiple of g, record the accelerometer values along each axis:

a_x = ______ g, a_y = ______ g, a_z = ______ g



From this, guess the orientation of one of the axes.

Flip the phone upside-down so that now the top edge of the smartphone is making contact with the lab table.

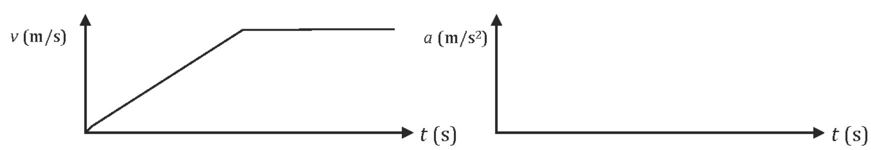
What happens to the accelerometer values?

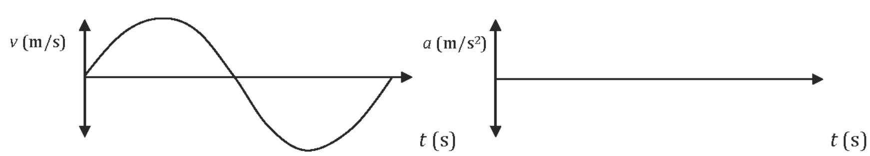
a_x = ______ g, a_y = ______ g, a_z = ______ g

Repeat the experiment for other edges of the smartphone so that you can determine the other two axes. Then, label each of the axes on the diagram to the left.

On the graphs of position – time below, try to predict and sketch what the corresponding velocity – time and acceleration — time graphs would look like.

On the graphs of velocity – time below, try to predict and sketch what the corresponding acceleration – time graphs would look like.





Meredith Lab 2

FALLING OBJECTS I ADDENDUM

PHYSICS 241

Name: ____________________________ Lab partners: ____________________________

Background

Recall that $x_f = x_i + v_i\Delta t + \frac{1}{2}a(\Delta t)^2$. For an object falling from height h, $x_f = 0$, $x_i = h$, $v_i = 0$ and $a = -g$, you can obtain the following:

$$h = \frac{1}{2}g(\Delta t)^2.$$

Drop your smartphone onto a pillow and determine the in-air flight time (Δt) using the accelerometer output. Using the height (h) and flight time (Δt) data, determine the acceleration due to gravity (g).

Procedure

Sketch what you think the acceleration versus time graph will look like when the smartphone is in free fall in the space provided. Be sure to mark the time period that the phone is in the air.

Prepare to drop your phone.

Record accelerometer data while the device is in free fall and determine the time of flight.

iPhone SensorLog

1. Open SensorLog.
2. Press the "ACC" button at the top of the screen to activate the accelerometer.
3. Press the play button (▸) to begin recording.
4. Hold the phone still for a few seconds at a height of 1.0 m before dropping.
5. Drop the phone onto the pillow and press the pause button (II) to stop recording.
6. Press the browse button ( ) and select the file that you have just recorded, which should be at the bottom of the list.
7. Email the file to yourself.
8. On the computer, open the .CSV file in Microsoft Excel. Select the columns "recordtime" and (while holding the CTRL key) "accelerationZ".
9. Graph the data by clicking the "Charts" tab and selecting Scatter: Straight-Lined Scatter. From the graph, determine the time of flight.

Android AndroSensor

1. Open AndroSensor.
2. Press the menu button ( ) on your phone.
3. Select "Settings". Scroll down to the option that allows you to change the speed of data collection and change this to "very fast".
4. Go back to the main AndroSensor screen and, on top of the accelerometer graph, swipe right. A "secret menu" appears on the left side of the screen. Press the record button (●).
5. Hold the phone still for a few seconds at a height of 1.0 m before dropping. Drop the phone onto the pillow and press the stop button (■) to stop recording.
6. A .CSV file will be saved to your SD drive. Email it to yourself. (If you don't have the ability to look at your files, you may need to download an app like ES File Explorer. Ask your instructor for help.)
7. On the computer, open the .CSV file in Microsoft Excel.
8. Select the columns for time and (while holding the CTRL key) the acceleration along the *z*-axis.
9. Graph the data by clicking the "Charts" tab and selecting Scatter: Straight-Lined Scatter. From the graph, determine the time of flight.

Repeat for heights of 0.6 and 0.3 m. Fill in the table below by recording your flight time under the "time" column" and then squaring this time and multiplying it by ½ for the middle column.

time (s)	**(1/2)*(time)^2**	**height (m)**
		1.0
		0.6
		0.3

We know that $h = \frac{1}{2}g(\Delta t)^2$. So if you plot h versus $\frac{1}{2}(\Delta t)^2$, your slope should be g. In a new Excel workbook, enter in the last two columns of the above table and graph them (again, using the scatterplot). Add a best-fit line and have it display the equation. Record your final slope here: g = ___________.

Meredith Lab 3

SIMPLE PENDULUM ADDENDUM

PHYSICS 241

Name: ______________________________ Lab partners:______________________________

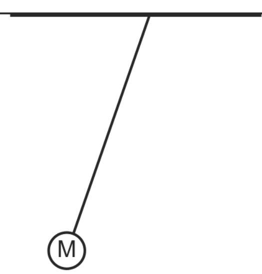
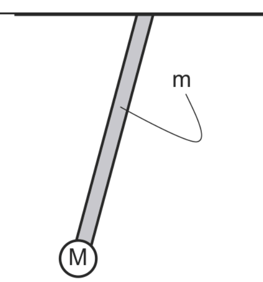
Background

A pendulum has only one resonant period and frequency, given by

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{L}} \quad \text{and} \quad T = 2\pi\sqrt{\frac{L}{g}},$$

where g is the acceleration due to gravity, L is the string length and $f = \frac{1}{T}$.

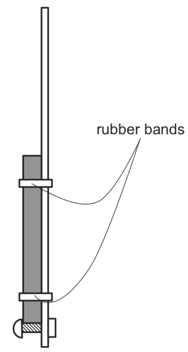
These equations work perfectly for simple pendulums, where all of the mass is concentrated in one place. For physical pendulums such as the one we're using in this lab, we must acknowledge that mass is distributed along the length of the rod and thus, the period is affected by some multiplicative factor, F, which depends on the mass of the rod.

Simple Pendulum	Physical Pendulum
	
Mass is concentrated at the bottom of the pendulum, in the bob. $T = 2\pi\sqrt{\frac{L}{g}}$	Mass is distributed over the rod (m) and there is also mass in the bob (M). $T = 2\pi F\sqrt{\frac{L}{g}}$

The purpose of this lab is to experimentally determine the acceleration due to gravity by experimentally timing the period of a pendulum with a known length. Period (T) is the time for one complete cycle.

Procedure

Note: Swing the mass so it oscillates in a plane without twisting or bumping anything. Do not let the pendulum holder move, which would add an external force to the system and adversely influence the period.



1. Attach your smartphone to the base of the pendulum rod, as shown in the side-view diagram at the right. You can rest the phone on the screw at the bottom of the rod.

2. Record the length, *L*, from the top of the pendulum rod to the center of the smartphone.

3. Record accelerometer data while the device is experiencing periodic motion.

iPhone SensorLog

1. Open SensorLog.
2. Press the "ACC" button at the top of the screen to activate the accelerometer.
3. Press the play button (▸) to begin recording.
4. Hold the phone still for a few seconds before setting into motion.
5. Begin the pendulum motion and press the pause button (⏸) to stop recording.
6. Press the browse button ( ) and select the file that you have just recorded, which should be at the bottom of the list.
7. Email the file to yourself.
8. On the computer, open the .CSV file in Microsoft Excel. Select the columns "recordtime" and (while holding the CTRL key) "accelerationZ".
9. Graph the data by clicking the "Charts" tab and selecting Scatter: Straight-Lined Scatter. From the graph, determine the time of flight.

Android AndroSensor

1. Open AndroSensor.
2. Press the menu button (☰) on your phone.
3. Select "Settings". Scroll down to the option that allows you to change the speed of data collection and change this to "very fast".
4. Go back to the main AndroSensor screen and, on top of the accelerometer graph, swipe right. A "secret menu" appears on the left side of the screen. Press the record button (●).
5. Set the smartphone pendulum into motion and, when you're ready, press the stop button (■) to stop recording.
6. A .CSV file will be saved to your SD drive. Email it to yourself. (If you don't have the ability to look at your files, you may need to download an app like ES File Explorer. Ask your instructor for help.)
7. On the computer, open the .CSV file in Microsoft Excel.
8. Select the columns for time and (while holding the CTRL key) the acceleration along the *z*-axis.
9. Graph the data by clicking the "Charts" tab and selecting Scatter: Straight-Lined Scatter. From the graph, determine the time of flight.

4. Determine the period from the accelerometer graphs by measuring the time that it takes to complete ten cycles and then dividing by ten. Record your measurements in the first row of the table below.

Measured *L* (m)	**Corrective factor, *F***	**Time for 10 cycles (s)**	***T*, the time for 1 cycle (s)**	**Experimental *g* (m/s^2)**
0.717	0.53			
0.617	0.57			
0.509	0.62			
0.416	0.67			

5. Answer the “Final questions” on page 59 of your lab manual.

Appendix D: Institutional Review Board Documents

Revised January 14, 2013

North Carolina State University
Institutional Review Board for the Use of Human Subjects in Research
SUBMISSION FOR NEW STUDIES

GENERAL INFORMATION

1.	**Date Submitted:** August 29, 2013
2.	**Title of Project:** Assessment of Student Gains in MyTech: Measurements Using Everyday Technologies
3.	**Principal Investigator:** Colleen Lanz
4.	**Principal Investigator Email:** cblanz@ncsu.edu
5.	**Department:** Physics
6.	**Campus Box Number: 8202**
7.	**Phone Number: 716-949-5070**
8.	**Faculty Sponsor Name if Student Submission:** Michael Paesler
9.	**Faculty Sponsor Email Address if Student Submission:** Paesler@ncsu.edu
10.	**Source of Funding** (Sponsor, Federal, External, etc)**: Sponsor** *If Externally funded, include sponsor name and university account number:*
	RANK: Colleen Lanz is a Ph.D. Candidate ☐ Faculty ☒ Student: ☐Undergraduate; ☐ Masters; or ☒PhD ☐ Other (specify): _____

As the principal investigator, my signature testifies that I have read and understood the University Policy and Procedures for the Use of Human Subjects in Research. I assure the Committee that all procedures performed under this project will be conducted exactly as outlined in the Proposal Narrative and that any modification to this protocol will be submitted to the Committee in the form of an amendment for its approval prior to implementation.

Electronic submissions to the IRB are considered signed via an electronic signature

Principal Investigator:

Colleen Lanz — August 29, 2013

(typed/printed name) (signature) (date)

As the faculty sponsor, my signature (or electronic submission) testifies that I have reviewed this application thoroughly and will oversee the research in its entirety. I hereby acknowledge my role as the ***principal investigator of record.***

Faculty Sponsor:

Dr. Michael Paesler — August 29, 2013

(typed/printed name) (signature) (date)

PLEASE COMPLETE AND E-MAIL TO: **irb-coordinator@ncsu.edu**

Please include consent forms and other study documents with your application and submit as one document. *Electronic submissions to the IRB are considered signed via an electronic signature. For student submissions this means that the faculty sponsor has reviewed the proposal prior to it being submitted and is copied on the submission.

****

For SPARCS office use only

Reviewer Decision (Expedited or Exempt Review)

☐ Exempt ☐ Approved ☐ Approved pending modifications ☐ Table

Expedited Review Category: ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8a ☐ 8b ☐ 8c ☐ 9

Revised January 14, 2013

Reviewer Name Signature Date

North Carolina State University
Institutional Review Board for the Use of Human Subjects in Research
GUIDELINES FOR A PROPOSAL NARRATIVE

In your narrative, address each of the topics outlined below. Every application for IRB review must contain a proposal narrative, and failure to follow these directions will result in delays in reviewing/processing the protocol.

A. INTRODUCTION

1. Briefly describe in lay language the purpose of the proposed research and why it is important.

We are allowing students to use their smartphone's built-in internal sensors to collect data in their physics labs instead of having to use traditional "black-box" equipment. We will then look at skill, attitudinal and technological anxiety shifts as a result of this implementation. This is an important study because smartphones are becoming more prevalent and we believe that they are a viable option for data collection devices in the lab. We hope that students are more comfortable using a smartphone app than traditional physics data collection equipment and that their attitudes about physics will reflect this.

2. If student research, indicate whether for a course, thesis, dissertation, or independent research.

This research is for my Ph.D. dissertation.

B. SUBJECT POPULATION

1. How many subjects will be involved in the research?

There will be 24 students involved in the study. (12 students will be in the control group using the traditional equipment and the other 12 will be using the MyTech app and lab suite.)

2. Describe how subjects will be recruited. Please provide the IRB with any recruitment materials that will be used.

Students have been "recruited" through MyPack Portal. The two courses (each of 12 students) are listed as normal lab options. The enrollment requirement for the class was that they must have a smartphone and would allow for pre-/post-testing as well as video recording of their performance in the lab.

3. List specific eligibility requirements for subjects (or describe screening procedures), including those criteria that would exclude otherwise acceptable subjects.

There were no other eligibility requirements beyond having a smartphone and allowing for video-recording.

4. Explain any sampling procedure that might exclude specific populations.

We will not be implementing any sampling procedure. We intend to use all of the data gathered from all 24 students.

5. Disclose any relationship between researcher and subjects - such as, teacher/student; employer/employee.

Colleen Lanz will be training the TA that will instruct the students in their lab. Beyond that, there is no interaction between researcher and subject.

6. Check any vulnerable populations included in study:

- ☐ minors (under age 18) - if so, have you included a line on the consent form for the parent/guardian signature
- ☐ fetuses
- ☐ pregnant women
- ☐ persons with mental, psychiatric or emotional disabilities
- ☐ persons with physical disabilities
- ☐ economically or educationally disadvantaged

- ☐ prisoners
- ☐ elderly
- ☐ students from a class taught by principal investigator
- ☐ other vulnerable population.

7. If any of the above are used, state the necessity for doing so. Please indicate the approximate age range of the minors to be involved.

C. PROCEDURES TO BE FOLLOWED

1. In lay language, describe completely all procedures to be followed during the course of the experimentation. Provide sufficient detail so that the Committee is able to assess potential risks to human subjects. In order for the IRB to completely understand the experience of the subjects in your project, please provide a detailed outline of everything subjects will experience as a result of participating in your project. Please be specific and include information on all aspects of the research, through subject recruitment and ending when the subject's role in the project is complete. All descriptions should include the informed consent process, interactions between the subjects and the researcher, and any tasks, tests, etc. that involve subjects. If the project involves more than one group of subjects (e.g. teachers and students, employees and supervisors), please make sure to provide descriptions for each subject group.

This project involves an assessment of a new set of laboratory equipment and curriculum known as MyTech (Measurements Using Everyday Technologies). First, the basics of the MyTech project will be described so that the study proposed for the IRB approval is clear and has context.

The MyTech project involves students using their "everyday technologies" (that is, their own personal smartphones) to collect data in their physics lab in lieu of traditional data collection equipment currently encountered in most physics labs. The MyTech lab curriculum is designed to use this equipment but keep its focus on the same physical concepts as the traditional lab. Not only is the current equipment expensive (prohibitively so for some colleges and universities), but it is confusing for students. Thus, the pedagogical burden shifts from important physics concepts to equipment usage. We believe that much of the frustration that students experience in the physics lab could be due to this equipment. Thus, the current "black box" interfaces provide both operational and attitudinal difficulties. Additionally, the technological anxiety experienced by students while using the current interface can lead to poor performance. Thus, by implementing their capable smartphones (which house a wide array of internal sensors, such as accelerometers, gyroscopes, cameras, etc.) we hope to see positive attitudinal and skill shifts and a negative shift in technological anxiety.

Our study is set apart from others that are also pursuing similar smartphone implementation in physics labs because we are not only creating a smartphone app and a corresponding curriculum for the lab but also ***studying the student outcomes as a result of their creation and implementation.***

This Fall 2013 semester, two sections of PY 205 labs (the introductory mechanics physics labs designed for mainly engineering majors) will be run in the Physics Education Group's Qualitative Education Research Lab (QERL). The first section (of twelve students) will be the MyTech group, which will use their smartphones for data collection. The second section (of twelve students) will be the control group, which will use the traditional equipment and lab curriculum and thus should be in a lab identical to their counterparts' lab.

The QERL classroom that we will be running the labs in is purpose-built for researchers studying students interacting in a group setting. It has a set of four standard-definition ceiling-mounted cameras and four table-top conference microphones to record audio. The observation room adjacent to the QERL also provides unobtrusive viewing of the study from behind two large one-way mirrors. All recorded video and audio data is captured in the observation room on a series of Apple Mac minis and Mac Pros. An audio mixer and matrix switcher provide the research with the opportunity to combine and condition audio from any microphone and reroute to any video capture device.

Students can volunteer to take the course on MyPack Portal. A special message appears for those that elect to attend one of the two sections described above that briefly outlines the study and asks them to volunteer their smartphone for the study. The message also mentions that they will be videorecorded and asked to take a few baseline tests throughout the course of the semester.

In the first meeting of the lab courses being studied, the principal investigator will take a few moments to explain the research project and what it will entail for participants. The information and consent forms will be distributed, and consent forms will be collected from students who choose to participate in the study. Participants will then be administered a series of tests and surveys. The first, the Colorado Learning Attitudes about Science Survey (CLASS), is a brief inventory of student attitudes regarding science and science courses. The CLASS has been adapted slightly to reflect their attitudes about labs specifically (to avoid confusion over whether the questions are asking about the lecture or lab portion of their courses). We will also administer the Test of Understanding Graphs in Kinematics (TUG-K), which was developed as a way of diagnosing students' understanding of graphs produced by computers in the first micro-computer based labs. Here, we are using the test to determine their understanding of graphs produced by their smartphones. Finally, we will administer a test of technological anxiety and usage, similar to the instrument developed by Robert K. Heinssen, et. al., the Computer Anxiety Rating Scale (CARS). We will change the terminology of this survey slightly so as to reflect more contemporary technological language. We will also ask a few questions about students usage of their smartphones.

The study participants will repeat the administration of the all of the surveys described above in the last week of lab to allow for measurements of gains/losses made during the course.

In addition to the surveys and assessment, study volunteers will also participate in the video analysis portion of the study. The information will be given during the first class, including explanations of privacy policies for the videos. The videos will allow us to compare the students performing in a traditional laboratory setting (with the typical "black-box" equipment) to those students performing in the MyTech setting (using smartphones as data collection devices). A Teaching Assistant (who is neither the Principle Investigator or Faculty Sponsor) will be present for both sections of the lab. Both the traditional and MyTech sections will perform their standard labs over the course of the semester and will be recorded by the four ceiling-mounted cameras and table-top microphones. The students will otherwise not do anything different than their normal laboratory routine. Prior research with this arrangement has shown that the recording process in not obtrusive and the students generally have no problem working on their lab assignments as usual. The door to the laboratory room will be shut and there are no other instructional laboratories nearby, thus it is extremely unlikely that students who did not volunteer for the video analysis portion will be recorded, as discussed in section D1.

Because the majority of students that would enroll in PY 205 labs are engineering students, it is safe to assume that female participants would be far outnumbered by their male counterparts. In order to bolster our female participant numbers, we are collaborating with Bill Schmidt, a physics professor at Meredith College, to also run three labs with his students. He has two sections of mechanics labs equivalent to our PY 205, one with 24 students and another with just under 24 students. Similar to the study performed on NC State's campus, one section will be a control group and the other will use the MyTech equipment and curriculum. Both will be filmed using tripod-mounted cameras giving an over-the-shoulder view of the group as well as a smaller tripod-mounted camera giving a closer video of the group from a different perspective with a microphone for sound recording. The control group will not do anything different from their normal lab routine. The MyTech group will use the MyTech data collection equipment and their labs will be altered slightly to allow for this. The same pre- and post-tests described above will be given on the first and last labs.

In all cases, the disruption to the normal course of performing the lab experiments will be minimized as much as possible, and for the most part students will simply do their normal lab assignments from day to day.

2. How much time will be required of each subject?

All aspects of the proposed study will take place during normally scheduled lab meeting times, so no time will be required of the subjects outside of the time they would spend in lab anyway. Within the lab time, the videotaping procedure will simply record the actions they would be taking normally, and the questionnaires and surveys will take only a nominal amount of time at the beginning and end of the semester.

D. POTENTIAL RISKS

1. State the potential risks (physical, psychological, financial, social, legal or other) connected with the proposed procedures and explain the steps taken to minimize these risks.

There are no foreseeable risks to the subject, and every attempt will be made to ensure anonymity and confidentiality

of the students, including those videotaped (as per sections D4 and D5). There does exist a chance that students who are not participants in the video and audio recording portion of the study are overheard on the microphone or walk across the camera's field of view. All data that accidentally captures voices or likenesses of students not participating in this portion of the study will be obscured.

2. Will there be a request for information that subjects might consider to be personal or sensitive (e.g. private behavior, economic status, sexual issues, religious beliefs, or other matters that if made public might impair their self-esteem or reputation or could reasonably place the subjects at risk of criminal or civil liability)?

There will be no requests for information from the subjects that could fall under these categories.

   a. If yes, please describe and explain the steps taken to minimize these risks.

   b. Could any of the study procedures produce stress or anxiety, or be considered offensive, threatening, or degrading? If yes, please describe why they are important and what arrangements have been made for handling an emotional reaction from the subject.

We will ensure that the pre- and post-tests (which could be considered a source of anxiety to some) will be as free of anxiety as possible. We will present them as tests that will only be used in the study and will not affect their grade outcome in the class. The only other study procedure that may be likely to produce stress or anxiety could be the videotaping process. If a volunteer subject does experience stress or anxiety during the process they will be free to call a stop to the recording process. No procedures could be considered offensive, threatening, or degrading.

3. How will data be recorded and stored?

Survey result data will be electronically collected and stored, and video data will be recorded to computer and also stored electronically. In both cases, the data will be stored on the secure drives belonging to the NC State Physics Education Research and Development group. These drives are firewall- and password-protected and locked in a secured room. The drives are backed up on a redundant server, which is also firewall- and password-protected and locked in a secure room.

   a. How will identifiers be used in study notes and other materials?

Identifiers will be used to connect data amongst the different pre- and post-tests to determine shifts in skills, attitudes and technological anxiety for different demographics of students. For the video analysis, if identifiers are necessary the study participants will be assigned pseudonyms for the purpose of the analysis. The correspondence between the pseudonyms and the subjects' identities will remain strictly confidential with the primary investigator.

   b. How will reports will be written, in aggregate terms, or will individual responses be described?

In the majority of cases, reports will be written in aggregate for the attitude survey and skill test. We may choose to focus on certain students that we feel are particularly noteworthy cases and track their individual progress in the class. The report will be of normalized gains in the assessments for the MyTech sections as compared to normalized gains for the control sections. Some individual responses may be described as examples in reports, but largely the video analysis will be reported on by using frequency measurements for different types of intra-group and group-TA interactions. Any individual responses described in reports will not include any identifying information of the student.

4. If audio or videotaping is done how will the tapes be stored and how/when will the tapes be destroyed at the conclusion of the study.

The recordings will be retained in the archives of the Physics Education Research and Development group. They will be stored as per D4, firewall and password protection in a locked room.

5. Is there any deception of the human subjects involved in this study? If yes, please describe why it is necessary and describe the debriefing procedures that have been arranged.

   There is no need for any deception in the study. The information given to the students will be very straightforward in explaining what data is being gathered and the goal of the study.

E. POTENTIAL BENEFITS

This does not include any form of compensation for participation.

1. What, if any, direct benefit is to be gained by the subject? If no direct benefit is expected, but indirect benefit may be expected (knowledge may be gained that could help others), please explain.

   There is not likely to be any direct benefit gained by the student, but the data being collected will be used to improve upon laboratory instruction and, if improvement in learning gains are shown, the procedures that led to these improvements will be further studied and disseminated, benefitting future laboratory students at NC State and elsewhere.

F. COMPENSATION

Please keep in mind that the logistics of providing compensation to your subjects (e.g., if your business office requires names of subjects who received compensation) may compromise anonymity or complicate confidentiality protections. If, while arranging for subject compensation, you must make changes to the anonymity or confidentiality provisions for your research, you must contact the IRB office prior to implementing those changes.

1. Explain compensation provisions if the subject withdraws prior to completion of the study.

   There is no lack of volunteer response for our study, as students were allowed to “opt out” of our videotaped MyTech and control sections so that they could attend a traditional lab. If there is a misunderstanding about the requirements of the study on the first day of class and students are hesitant to volunteer either their data for the study or their smartphones for use in the lab, we may offer a compensation for each lab in which they participate.
   If a subject withdraws prior to the completion of the study, the compensation will be disbursed on a case-by-case basis as they participate.

2. If class credit will be given, list the amount and alternative ways to earn the same amount of credit.

   Class credit will be given for the lab following the normal grading procedures regardless of whether the students participate in any aspect of the study. In other words, student will not receive any extra class credit by participating in this study.

G COLLABORATORS

1. If you anticipate that additional investigators (other than those named on **Cover Page**) may be involved in this research, list them here indicating their institution, department and phone number.

   Bing Zhang, NC State Physics Department, 919-513-7214
   Will Sams, NC State Physics Department, 919-513-7214
   Bill Schmidt, Meredith Physics Department, 919-760-8616
   Bob Beichner, NC State Physics Department, 919-515-7226
   Brad Mehlenbacher, NC State Leadership Policy & Adult & Higher Education Department, 919-515-6242

2. Will anyone besides the PI or the research team have access to the data (including completed surveys) from the moment they are collected until they are destroyed.

   Other members of the Physics Education Research and Development group can access the servers on which the data will be stored. All members of this group have extensive training about data security, including ethics training and the CITI training program about human subjects. Group members follow strict security protocols regarding data security and permissions.

H. CONFLICT OF INTEREST

1. Do you have a significant financial interest or other conflict of interest in the sponsor of this project? *No*

2. Does your current conflicts of interest management plan include this relationship and is it being properly followed? ______

I. ADDITIONAL INFORMATION

1. If a questionnaire, survey or interview instrument is to be used, attach a copy to this proposal.
2. Attach a copy of the informed consent form to this proposal.
3. Please provide any additional materials that may aid the IRB in making its decision.

J. HUMAN SUBJECT ETHICS TRAINING

*Please consider taking the Collaborative Institutional Training Initiative (CITI), a free, comprehensive ethics training program for researchers conducting research with human subjects. Just click on the underlined link.

North Carolina State University
INFORMED CONSENT FORM for RESEARCH

Assessment of Student Gains in MyTech: Measurements Using Everyday Technologies

Colleen Lanz Michael Paesler (faculty sponsor)

What are some general things you should know about research studies?

You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time without penalty. The purpose of research studies is to gain a better understanding of a certain topic or issue. You are not guaranteed any personal benefits from being in a study. Research studies also may pose risks to those that participate. In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above.

What is the purpose of this study?

The NC State Physics Department is in the process of developing a new type of lab course for introductory physics classes. One aspect of this new lab course is to provide students with the option of using their own smartphones' internal sensors for data collection. This will be accomplished by using a MyTech-enabled app and a series of labs adapted for the usage of this technology. The purpose of this study is to evaluate this aspect of the new lab course by comparing it to a traditional lab that uses typical data collection equipment, such as the PASCO Science Workshop 750 interface with DataStudio software. To accomplish this, audio and video recordings will be made of participants as they go through the normal process of performing weekly lab activities, and the researchers will analyze the recordings to make comparisons between the different types of labs.

What will happen if you take part in the study?

If you agree to participate in this study, you will be placed in a lab group of other participants and will conduct your lab activities as normal.

If you are in the MyTech section, part of the normal process of conducting labs in this course involves using your own smartphone (or the smartphone of a group member) for data collection. The smartphone user will download an app like SensorLog to allow for immediate access to the raw data obtained from the internal sensors (such as the accelerometer, gyroscope, etc.) of the smartphone. The data can then be easily emailed to the group for further analysis on a computer, just as one would do in a traditional lab. You will also be asked to complete a few questionnaires to determine your skill, attitudes about science and technological anxiety on the first and last lab days.

If you are in the control section, your lab should not differ in any way from that of your counterparts other than the fact that you will be asked to complete a few questionnaires to determine your skill, attitudes about science and technological anxiety on the first and last lab days.

This room is equipped with video and audio recording equipment so that students can be recorded while participating in educational activities. You will not need to do anything different than you would normally do in the course of participating in your lab course this semester except possibly using your smartphone (or that of a group member) to take data. This will require none of your time outside of scheduled class time. You will be recorded during each lab session. The study will conclude at the end of the lab course.

Risks

There are no foreseeable risks to you for participating in this study. No part of the recording or analysis process will have any impact on your course or lab grade, and none of your professors or instructors will see the recordings or their findings. The recordings are for informational and research use only, they will only be available to the researchers conducting the study, and the recordings and findings will be confidential (see below).

Benefits

There is not likely to be any benefit to you for participating in this study, but your participation could benefit others. The benefits that are gained from this study involve the improvement of the way laboratory courses are taught, here at NC State and possibly beyond, and so may benefit future students who enroll in this or other laboratory courses.

Confidentiality

The information in the study records will be kept confidential to the full extent allowed by law. Data will be stored securely in an electronic format on a server that is password and firewall protected and locked in a secure room. No reference will be made in oral or written reports that could link you to the study. In any case in which reference is made to individuals in the study, false names will be used with no way of identifying any participant. In any case where a person outside of the study may see stills or scenes from the recordings, all faces will be obscured and anything that could identify a participant will be excluded. You may be asked to identify yourself on the questionnaires so that we can match up your pre- and post-survey results. Your name will *not* be seen by anyone other than the Principal Investigator and will not be published in the research results. The recordings will not be used in any manner not described in this document without explicit written consent from each participant.

Compensation

There will be no compensation for participating in this lab.

What if you are a NCSU student?

Participation in this study is not a course requirement and your participation or lack thereof, will not affect your class standing or grades at NC State.

What if you have questions about this study?

If you have questions at any time about the study or the procedures, you may contact the researcher, Colleen Lanz at cblanz@ncsu.edu, or 919-513-7214, or Riddick Hall 224A.

What if you have questions about your rights as a research participant?

If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Deb Paxton, Regulatory Compliance Administrator, Box 7514, NCSU Campus (919-515-4514).

Consent To Participate

"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled."

Subject's signature_______________________________________ **Date** _________________
Investigator's signature__________________________________ **Date** _________________

North Carolina State Institutional Review Board
STUDY REVISION REQUEST FORM

To have a study revision approved, please complete this form and send it to ***ncsuirboffice@ncsu.edu*** *with any necessary attachments.*

Study Information	
IRB #:	IRB Approval Expiration Date:
Project Title: **Assessment of Student Gains in MyTech: Measurements using everydaY TECHnologies**	
Principal Investigator(s): **Colleen Lanz** E-mail Address for Principal Investigator(s): **cblanz@ncsu.edu** Best Contact Phone Number: **919-513-7214** Faculty Sponsor(s): **Dr. Michael A. Paesler** E-mail Address for Faculty Sponsor: **paesler@ncsu.edu**	

IMPORTANT NOTES:

- **Approval for a revision does not change the IRB approval date of your study.**
- **Do NOT attach a revised protocol. If revisions dramatically change your approved protocol, you may be asked to submit a new or revised protocol later.**
- **Please make sure to submit all changes to your study materials with revisions/edits clearly tracked or highlighted.**
- **In the body of this form, please indicate what attachments pertain to what revision.**

****
(For IRB office use only)

Review Received: Administrative Expedited Full Board

Review Decision: Approve Approve with Modifications Not Approved

Review Notes:

Reviewer: ____________________Signature: ____________________ Date: ____________

1

1. **Summarize all requested changes to your study and note the justification for each change.**
   We intend to ask a few additional questions at the beginning and the end of the semester about students' understanding of the sensors inside their smartphones (or, in the case of the control group, the sensors used in the lab). We are adding these questions to determine whether or not students that use smartphones for data collection are gaining a deeper understanding of their laboratory equipment as compared to the students in the section that uses the traditional equipment.

2. **Do the requested changes impact the study <u>design or methodology</u> (examples: addition of data collection method, audio/video recording)?**
   No ☒ Yes ☐
   If yes, please describe:

3. **Do the requested changes impact the <u>eligibility criteria</u> of participants?**
   No ☒ Yes ☐
   If yes, please describe:

4. **Do the requested changes affect the <u>number of participants</u> recruited and/or enrolled?**
   No ☒ Yes ☐
   If yes, please describe:

5. **Are requested changes <u>limited to editorial and/or administrative</u> changes (examples: change in research staff, wording of informed consent, survey revisions)?**
   No ☐ Yes ☒
   If yes, please describe and send revised forms with revisions tracked/highlighted: **We will ask students at the end of the semester how well they understand the data collection process by asking a few direct questions about how the sensors they used work. I have attached the draft version of this questionnaire. We will submit the final version to the IRB prior to administering the test to students at the end of the semester.**

6. **Do the requested changes affect <u>risks and/or benefits</u> expected from participating in the study?**
   No ☒ Yes ☐
   If yes, please describe:

7. **Do the requested changes affect anonymity and/or confidentiality?**
   No ☒ Yes ☐
   If yes, please describe:

8. **Is there any other information you would like for us to know?**

North Carolina State Institutional Review Board
STUDY REVISION REQUEST FORM

To have a study revision approved, please complete this form and send it to ***ncsuirboffice@ncsu.edu*** *with any necessary attachments.*

Study Information	
IRB #: 3483	IRB Approval Expiration Date:
Project Title: **Assessment of Student Gains in MyTech: Measurements using everydaY TECHnologies**	
Principal Investigator(s): **Colleen Lanz** E-mail Address for Principal Investigator(s): **cblanz@ncsu.edu** Best Contact Phone Number: **919-513-7214** Faculty Sponsor(s): **Dr. Michael A. Paesler** E-mail Address for Faculty Sponsor: **paesler@ncsu.edu**	

IMPORTANT NOTES:
- **Approval for a revision does not change the IRB approval date of your study.**
- **Do NOT attach a revised protocol. If revisions dramatically change your approved protocol, you may be asked to submit a new or revised protocol later.**
- **Please make sure to submit all changes to your study materials with revisions/edits clearly tracked or highlighted.**
- **In the body of this form, please indicate what attachments pertain to what revision.**

****
(For IRB office use only)

Review Received: Administrative Expedited Full Board

Review Decision: Approve Approve with Modifications Not Approved

Review Notes:

Reviewer: _____________________Signature: _____________________ Date: ____________

1

1. **Summarize all requested changes to your study and note the justification for each change.**

   We would like to ask students for their opinions on the smartphone app that they have used throughout the semester. This involves a written survey that should take about ten minutes to complete. There are no right or wrong answers, and the students will not receive a grade for their work. The survey will only be administered to the students in the smartphone section of the lab (not the control section). We are adding these questions to determine how we can improve the design of the app.

2. **Do the requested changes impact the study design or methodology (examples: addition of data collection method, audio/video recording)?**
   No ☒ Yes ☐
   If yes, please describe:

3. **Do the requested changes impact the eligibility criteria of participants?**
   No ☒ Yes ☐
   If yes, please describe:

4. **Do the requested changes affect the number of participants recruited and/or enrolled?**
   No ☒ Yes ☐
   If yes, please describe:

5. **Are requested changes limited to editorial and/or administrative changes (examples: change in research staff, wording of informed consent, survey revisions)?**
   No ☐ Yes ☒
   If yes, please describe and send revised forms with revisions tracked/highlighted: **We are interested in students' responses as we begin designing our own app. I have attached the finalized version of this questionnaire.**

6. **Do the requested changes affect risks and/or benefits expected from participating in the study?**
   No ☒ Yes ☐
   If yes, please describe:

7. **Do the requested changes affect anonymity and/or confidentiality?**
   No ☒ Yes ☐
   If yes, please describe:

8. **Is there any other information you would like for us to know?**

Appendix E: Pendulum VPython Code

```
# Solve the pendulum using numerical approximation
# Copyright (c) 2008 David M. Harrison

# Adapted by Colleen Lanz Countryman 2015
# Features of new version:
#
#   displays tangential "force" and radial "force" arrows when
student clicks on support
#   pauses animation upon click
#   graphs (nonscaled) versions of the tangential force and radial
force experienced by smartphone

# The next line is an internal revision control id:
# $Date: 2008/05/10 10:33:45 $, $Revision: 1.1 $

# Import the visual library
from visual import *
from visual.graph import *

def pause():
    while True:
        rate(50)
        if scene.mouse.events:
            m = scene.mouse.getevent()
```

```
            if m.click == 'left': return
        elif scene.kb.keys:
            k = scene.kb.getkey()
            return

# The initial angle in radians.
theta = pi/6.0

# The initial angular velocity
omega = 0

# Set g and the length of the pendulum
g = 9.80
L = 1.00

# These  four lines control the size of the window of
# the animation and the scale. The details of these lines
# are not important for our purposes.
scene.autoscale = 0
scene.height = 600
scene.width = 600
scene.range = vector(2.0,2.0,2.0)

# The addition of graphs of a_tan (tangential) and FT (radial)
atangraph = gcurve(color=color.red)
FTgraph = gcurve(color=color.cyan)
```

```
#
# Now we build the pendulum which we will animate.
#

# The support for the pendulum
support = cylinder( pos = (0, 0, -0.5), axis = (0,0,1), radius =
0.02)

# The "frame" construct groups two or more objects into a single
one.
# Here we group the cylinder and the sphere into a single object
# which is the pendulum.
pendulum = frame()
cylinder(frame=pendulum, pos=(0,0,0), radius=0.01, length=1,
material=materials.rough)
#bob=sphere(frame=pendulum, pos=(1,0,0), radius=0.1,
color=color.red)
bob=box(pos=(1,0,0),size=(.4,.05,.3),frame=pendulum)

# Position the pendulum.
pendulum.pos = (0,0,0)

# arrow visibility
arrowsvisible = True

# Rotate the pendulum about the z axis. Note that VPython measures
```

```
    # angles with respect to the x (horizontal) axis. We are measuring
    # angles with respect to the vertical (-y axis) so we subtract
    # pi/2.0 radians from the angle.
    pendulum.rotate(axis = (0,0,1), angle = theta - pi/2.0)

    # The time
    t = 0.
    #velocityarrow = arrow(frame=pendulum,color=color.red)
    forcearrow = arrow(frame=pendulum,color=color.cyan,
visible=arrowsvisible)
    alphaarrow = arrow(frame=pendulum,color=color.red,
visible=arrowsvisible)

    # Below we will want to store the old value of the time.
    # Set it the "impossible" value of -1 initially.
    t_old = -1.

    # The time step
    dt = 0.00005

    # scaling for arrow length appropriateness
    alphascale = 0.1
    forcescale = 0.06
    alphagraphscale = 0.05
    forcegraphscale = 0.33
```

```
# The value "1" is equivalent to true. So this causes the while
# loop to run forever.
while 1:

    # Set the rate of the animation in frames per second
    rate(1/dt)

    # Pause the animation with a mouse click
    if scene.mouse.clicked:
        m = scene.mouse.getclick()
        if m.pick is support:
        #if scene.mouse.getclick()
            arrowsvisible = not arrowsvisible
            forcearrow.visible = arrowsvisible
            alphaarrow.visible = arrowsvisible
        else:
            while True:
                if scene.mouse.clicked:
                    scene.mouse.getclick()
                    break



    # The angular acceleration, i.e. the second derivative of the
    # angle with respect to time.
    alpha = -(g/L) * sin(theta)
```

```
        # The new value of the angular velocity
        omega = omega + alpha * dt
        vtan = omega*L
        force = (1/L)*vtan**2 + g*cos(theta)
        #velocityarrow.pos = bob.pos
        #velocityarrow.axis = .1*vtan*vector(0,1,0)
        alphaarrow.pos = bob.pos
        alphaarrow.axis = alphascale*alpha*vector(0,1,0)
        forcearrow.pos = bob.pos
        forcearrow.axis = forcescale*force*vector(-1,0,0)



        # The change in the angle of the pendulum
        d_theta = omega * dt

        # A rough and ready way to estimate the period of the
oscillation.
        # It the angle is positive and adding d_theta to it will make
        # it negative, then it is going through the vertical
        # from right to left.
        if(theta > 0 and theta + d_theta < 0) :
            # If t_old is > 0, then this is not the first cycle of
            # the oscillation. The difference between t and t_old
            # is the period within the resolution of the time step dt
            # and rounding errors. Print the period.
            if(t_old > 0):
```

```
            #print "Estimated Period =", t - t_old, "s"
        # Store the current value of the time in t_old
            t_old = t

    # Rotate the pendulum about the z axis by the change in the angle
    pendulum.rotate(axis = (0,0,1), angle = d_theta)

    # Update the value of the angle
    theta = theta + d_theta

    # Update the time
    t = t + dt

    # Graph it
    atangraph.plot(pos=(t,-alpha/(L)))
    FTgraph.plot(pos=(t,-force))
```