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Physics Education Research on Inexpensive Active-Learning Lab Modules

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Physics Education Research on Inexpensive Active-Learning Lab Modules

An Interactive Qualifying Project

Submitted to the Faculty

of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

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Nancy A. Burnham PhD, Advisor

This report represents the work of WPI undergraduate students submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on its website without editorial or peer review. For more information about the projects program at WPI, please see http://www.wpi.edu/academics/ugradstudies/project-learning.
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Abstract

Active learning strategies, including hands-on activities and lab work, have proved to be beneficial to student comprehension and success in physics classrooms. Only 47% of high school physics classes are taught by a teacher with a degree in physics. This project aims to design three modular, inexpensive, and demonstrative lab modules in introductory mechanics that are easy to implement and should enhance student knowledge in friction, conservation of energy, and torque, because students show weakness in these areas. Other WPI physics students tested the lab kits, and then feedback on their efficacy was used to enhance the lab modules. In the future, another project will carry out these labs in a high school and suggest these lab modules to low-income schools.

Authorship

All authors contributed equally to the project. Megan Varney designed the friction lab, Corinne Rywalt designed the conservation of energy lab, Zoe Mutton designed the torque lab, and all authors wrote sections relating to the lab module that they designed. All authors have reviewed the final report.

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1. Introduction

The overall goal of this project was to design modular, inexpensive, and demonstrative lab modules to enhance student knowledge in introductory mechanics. The labs, including an accompanying worksheet for students to complete, would be easily implementable in classrooms, take 20-30 minutes to complete, and be cost effective. Once designed, the labs would be tested with high school teachers and students to demonstrate that they are easily implementable, easy for students to understand, and effectively demonstrate their respective learning objectives. This Interactive Qualifying Project (IQP) team designed three lab modules in friction, conservation of energy, and torque. Administrative constraints kept the team from evaluating the labs in a high school classroom, but some feedback was collected from surveying undergraduate physics students through an event with WPI’s chapter of the Society of Physics Students (SPS).

Active learning strategies have been proven to give students a deeper, more conceptual understanding of course material, decreasing the failure rate of introductory courses by more than 10% (6, 7). A conceptual gain is seen in physics classrooms that implement active learning strategies, and the labs that often compliment introductory physics courses aid students in understanding physics concepts and other laboratory skills (11, 13). Despite the benefits of providing lab activities to students, traditional lab equipment remains costly for an institution to purchase and store (22). A primary goal of this project was to make the lab modules as inexpensive as possible; this would allow some high schools that can not afford traditional lab equipment to implement these lab modules and provide some of the benefits of active learning to their students.
While deciding which topics in introductory mechanics to design lab modules for, the IQP team used several resources: results from the Mechanics Baseline Test (MBT), their personal experiences as Peer Learning Assistants (PLAs) for an active learning course in introductory mechanics, and suggestions from their past high school physics instructors (50). One lab module focused on friction, the only concept which students performed worse in on the MBT administered after the course than on the pre-course MBT; the lab used a simple block-on-a-ramp set-up. The second lab module focused on conservation of energy and used a mass on the end of a spring to show that the sum of kinetic and potential energy is constant. The final lab module focused on torque and used a ruler, pencil, and spring scale to determine the force needed at various distances and angles to the ruler to counteract a constant torque.

Because the IQP team was unable to do trial runs of the lab modules with high school students, they hosted an event with WPI’s chapter of SPS to have undergraduate physics students test the labs. Each member of SPS was given as much time as they needed to work with the lab set up and accompanying worksheet; they then completed a survey to give feedback to help improve the labs for implementation in a high school environment. Overall, the members of SPS rated the lab modules and worksheets highly. Many of the suggestions to the worksheets were for grammatical mistakes and to resolve ambiguity in the instructions and questions. Other suggestions, many of which were included in revised versions of the worksheets, included expanding upon the equations used and including diagrams of the lab set up.

In the end, the project team was able to design three lab modules to fill the gap in existing physics education research that they identified. The target audience of the lab modules is high school students, so it is important that the labs go through proper trial runs in a high school
classroom environment before being completed and published. Therefore, the current project team also worked to complete a well-detailed appendix to be used as a reference for a future project team; this appendix includes a proposed goal for a future project, a suggested timeline, and any forms required by WPI, Worcester Public Schools, or the Commonwealth of Massachusetts in order to do work in the high schools.

This report includes an analysis of physics education literature, particularly concerning active learning, labs, and incorporating smartphones into lectures and lab activities. The authors then discuss the methods they used to design each of the three lab modules and test the labs with undergraduate physics students. An in-depth description of each lab module is given, including the materials used as well as protocol and conceptual questions used in the accompanying worksheets. The authors give a summary of the results from the event with WPI’s chapter of SPS, and discuss the revisions made to the lab modules. The report concludes with a discussion of the issues with doing trial runs at high schools, the limitations of having results from undergraduate students, and a summary of the plan for a future project to perform trials with the target demographic.
2. Literature Review

The No Child Left Behind Act of 2001 was put into place in an effort to improve the American education system (1). However, recent data show that the United States is still moderately average in comparison to other developed countries in the areas of science, mathematics, and reading, as shown in Figure 1. The Programme for International Student Assessment (PISA) is a test administered every three years to gauge how well 15-year-olds across the world perform in these areas. The most recent PISA results are from 2015, and the U.S. placed 38th out of 71 countries in mathematics and 24th in science. In addition, 35 countries scored significantly higher in mathematics, and 17 scored significantly higher in science than the United States (2).

![Figure 1: Results from the Programme for International Student Assessment (PISA) in 2015. The U.S. received average scores in science, math, and reading. From Reference 2.](image)

These data, along with the growing need to fill positions in the STEM industry, are cause to call for an improved STEM education curriculum to better prepare students for a highly tech-integrated world, but this is something that is easier said than done. Physics education is particularly lacking in the United States. As shown in Figure 2, the percentage of students who
graduate high school each year has been significantly higher in the last 50 years than in the late 19th and early 20th century, rising from less than 5% in 1880 to about 80% in 2012. In 1880, approximately all high school graduates had taken a physics course by the time they graduated. However, in 2012, only about 3 out of every 8 high school graduates took physics, showing that even though the percentage of students completing high school has increased significantly, the percentage of graduates who have taken physics has decreased (3). Unfortunately, only 47% of high school physics classes are taught by a teacher with a degree in that subject, while 73% of biology classes and 80% of humanities classes have that benefit. As a result, many schools have difficulty filling positions for physics teachers and may not offer physics at all (4). The aim of this project is to make physics education more accessible to these schools by offering simple, cost-effective, hands-on lab modules that do not require an instructor with an advanced degree to effectively teach students.

![Figure 2: Proportion of high school graduates who took physics in high school from 1880 to 2012. The number of students who graduate high school is increasing, but the number of students who take physics is increasing less quickly. From Reference 3.](image)

2.1 Introduction to Active Learning

In the last several decades, physics education research has become a largely growing field, particularly concerning applications of active learning to physics classrooms. Active
learning has been implemented in a wide variety of STEM fields, and education research supports it as an effective way to improve student performance in courses. A large range of active learning techniques have been implemented, with the most successful shown to be techniques that encourage cooperative learning and collaboration with other students (5). Effective active learning has been shown to lead to reduced failure rates, with only about 20% of students in an active learning environment failing the course, compared to about one-third of students in traditional classrooms failing the course, as shown in Figure 3 (6).

![Figure 3: Active learning classrooms are shown to have a lower failure rate than traditional lecture classrooms. The failure rate of students decreases by about 11-12% in an active learning classroom, decreasing from about one-third of students failing a lecture-style class to about 20% failing in an active learning environment. From Reference 6.](image)

A higher level of student success is likely caused by active learning allowing students to gain a deeper level of understanding of the material covered in the course. Traditional classrooms cover more quantitative material, helping the students learn how to solve problems and obtain numerical results. On the other hand, active learning classrooms are more qualitative, leading to a higher level of conceptual knowledge and a deeper understanding of the studied phenomena (7). Active learning can also increase communication among students, as well as between the students and the instructor. An active learning classroom that uses a classroom communication system, such as a clicker, keeps the students engaged by allowing each of them
to participate in lecture. This system allows the instructor to assess how well the students are understanding the material in real time and focus more on topics that students struggle with as necessary (8).

Because active learning has been shown to have numerous benefits, students with both a medium (3.0-3.9) GPA and high (4.0-4.5) GPA have reported having a positive attitude towards active learning classrooms. While students with high GPAs also had positive attitudes towards traditional classrooms, these students rated active learning classrooms higher than traditional methods. Medium GPA students rated traditional classrooms very poorly (9). Furthermore, students who take a course in an active learning classroom report a higher average level of confidence in the course material than students who take the same course in a traditional classroom. One study showed that this higher level of confidence in the course material has a positive correlation with the student’s success in the course (10).

2.2 Active Learning in Physics Classrooms

Active learning has been applied in physics classrooms at a wide range of levels, including in high schools, colleges, and universities. Students at every level of education showed a larger increase in conceptual knowledge after taking a class taught using an active learning classroom as compared to a traditional lecture classroom, as shown in Figure 4 (11).
A common issue in traditional physics classrooms is a discrepancy between how students think about problems and how instructors teach. Many students go into a physics course not expecting to need to know anything beyond how to use the formulas given to them in lecture. They passively take lecture notes and simply memorize the information and equations, but do not analyze the underlying concepts in order to fully understand them. This leads to students believing that topics in physics are unconnected and that the ideas they are taught are not related to real physical experiences. For example, many students say that the only thing they learn from the derivation of a formula is that the equation is valid and okay to use in problems (12). In active learning environments, instructors have the ability to gather more information about how well the students are understanding the material by working with students one-on-one, in small groups, or through a classroom communication system. Furthermore, if the active learning classroom implements a lab activity, the students have an opportunity to see common physics
scenarios in real time and under non-ideal circumstances. This aids the students in making connections between the physical concepts and mathematical equations that they are taught in lecture (13).

Another challenge in traditional classrooms is keeping students engaged throughout the lecture. Passive listening is not an effective way of absorbing, analyzing, and learning information. Instead, students must be engrossed in the material they are being taught through hands-on activities, demonstrations, and questions that help them make connections with important concepts and physical scenarios. Lab demonstrations are an important opportunity for instructors to show students why the lecture material is important for them to learn when considering the real world (14). Fortunately, the past several decades have been marked by a large increase in the complexity and availability of technology. Because of these advances, a wider range of introductory physics labs and demonstrations have become available, specifically with the use of data collecting hardware and software (15). However, some schools are unable to provide lab equipment due to lack of space, time, or funds. If labs are unavailable, guided worksheets are another beneficial way to keep students engaged in their learning; these show the highest level of success when they encourage students to collaborate with each other, a key part of effective active learning. These interactions lead to a higher level of engagement and better problem solving (16).

Despite active learning being well supported by education research as causing positive correlations with student understanding and success, most classrooms still implement strictly traditional learning methods. One study shows that instructors do not use active learning techniques, despite awareness of the benefits of student-centered instruction (17). Even outside
of applications of active learning, few physics classrooms follow pedagogical practices that have
been shown to be effective in physics education research (18). One study shows that some
instructors believe that active learning methods, such as labs, are not beneficial to student
success on exams despite the extensive research done in this field. Instead, these instructors rated
pen-and-paper problem solving and the use of a textbook as their preferred methods for teaching
physics concepts, particularly in secondary schools (19).

2.3 Technology in Active Learning

Communication and engagement, two of the facets of effective active learning, are
encouraged and facilitated by the use of technology in the classroom. The use of individual
response devices, such as handheld clickers, can give instructors real-time insight into how their
students are comprehending material and keep students engaged by forcing them to think about
the concepts they have learned. A majority of clickers used today have keypads that allow
students to either type in their responses or answer multiple choice questions. The use of clickers
in a large classroom setting, such as the average university physics course, gives instructors the
ability to gauge which students were able to comprehend the material taught just prior. This
prompt feedback from large classes provides an alternative to individual conversations with
students that would take a significant amount of scheduled class time (20).

An added benefit of using a clicker-style device in a classroom is the incentive for the
students to attend class everyday. Figure 5 shows that the average attendance of a class that
utilizes some form of audience response system (ARS), such as a clicker, is higher than the
average attendance for a classroom that does not utilize an ARS. On days students do not take an
exam, average attendance rises from about 60% to about 90% when the use of an ARS is
implemented in the classroom (20). The instructor may decide to use an ARS in order to do mandatory daily quizzes that act as an attendance check, which will incentivize students to attend class in order to get their attendance points. Depending on the ARS used in the class, the instructor may even use the system to give graded quizzes.

![Average Attendance of a class using an ARS vs. a class not using an ARS](image)

*Figure 5: Average attendance of a class using an audience response system (ARS) vs. the average attendance of a class that does not use an ARS. On average, a class that engages the students using an ARS has a higher attendance, particularly on days without an exam. From Reference 20.*

There are several options available to instructors implementing clicker-style responses into their teaching; many of these are supported by smartphones and/or applications, eliminating an investment in a clicker system and complimentary software. Instead, free websites and applications can be used with the combination of students’ personal mobile devices. For example, the web-based application *Socrative* was used intermittently throughout lectures as a break from absorbing information and as a tool to understand the students’ level of comprehension, as well as encourage collaboration amongst the students. 94% of surveyed students agreed that the use of *Socrative* stimulated interaction with their partners, and 91% percent agreed that the questions helped them realize what material they understood (21).
A key part of the active learning environment is classroom arrangement. Technologies such as projectors, laptop or tablet computers, and SMART Boards® allow for material to be displayed on multiple screens at once as well as interacted with through the use of individual response systems like clickers. Many active learning classrooms seat students around tables in groups spaced throughout a room of multiple projectors and boards to keep both content and collaboration accessible during class time. Figure 6 shows the diagram of an active learning classroom at SoongSil University, designed to allow students to work in groups and collaborate with one another without losing access to material (9). A majority of the technology used in this type of active learning classroom is commonly used in large lecture classes today, so the implementation of multiple screens enhances the environment without hindering an instructor with the use of a new interface.

Figure 6: The classroom diagram above shows the layout of the Active Learning Classroom at SoongSil University, with LCD and projector screens as well as computers at each table, utilizing technology to increase accessibility and interactivity of the material. From Reference 9.
2.4 How Labs Benefit Student Understanding

Some traditional classrooms offer a lab section in addition to lecture times. Many educators believe that these lab sections are beneficial because they offer a wide variety of opportunities for the students. These include the ability to stimulate interest in the topic, learn general laboratory and experimental skills, and encourage social skills and collaboration among students (22). Furthermore, the lab sections allow students to discover and better understand physics concepts. This is because they are able to see concepts arise from real events rather than just from a set of theories and mathematical equations (13). For example, a study conducted by Rosenquist & McDermott in 1986 focused on helping college students understand basic concepts in kinematics. These topics include instantaneous velocity as a limit, distinguishing between position, velocity, and acceleration, and making connections among graphs, concepts, and motions. To do so, they identified specific challenges that students face and developed a curriculum to respond to their needs. One challenge in particular was that students had trouble choosing which aspect of the graph contains the information that they are being asked for, such as choosing between the height and slope at a given time. Through their experience, Rosenquist & McDermott concluded that students were best able to succeed when they could watch kinematics happen in real time and practice making connections between different equations, physical phenomena, and graphs (23). Early studies suggested that substituting just one active learning lab into a course had a significant difference on how students performed in these areas and on their exams (24).
2.5 How Labs Improve Other Skills

While some studies have shown labs improve student exam scores by raising student comprehension in physics concepts, others demonstrate that labs may have little, if any, positive effect on student exam performance. Figure 7 shows one study that determined the mean lab benefit for three different introductory physics courses across three schools. All nine courses had a very low mean lab benefit, with three of the nine courses having a negative benefit. These results suggest that labs may not increase student exam scores as much as they were originally believed to (25). However, labs are still a beneficial tool in introductory physics courses because they teach students a variety of other skills. Labs are a useful approach to getting students engaged in the lecture material, because they can perform hands-on activities or simulations that make them think about the concepts being presented. Students can also gain important experimental skills such as data collection, data analysis, the ability to predict the outcomes of an experiment, and the ability to properly draw and analyze kinematics graph (26-27). Finally, labs can give students an opportunity to collaborate with others, aiding them in improving communication and constructing positive group dynamics. Over time, this collaboration becomes natural dialogue that is effective in improving learning (28).

Figure 7: The mean lab benefit on final exams in nine courses at three institutions. Error bars represent the standard error. Labs in general may not provide much benefit in improving exam scores in introductory physics courses. From Reference 25.
The past several decades in physics education have been marked by a decrease in the number of students who major in physics (15). Despite this decrease, labs for introductory physics courses remain relevant for all STEM majors. The skills learned in introductory physics labs are not only applicable to the physics lab and course that the students are immediately in, but can also be applied to any STEM major’s education and career. Students studying any field of science or engineering must be able to handle basic experimental set-ups and collaborate in teams (29). Introductory physics lab courses are shifting focus from conceptual demonstrations to building experimental skills. Developing these skills has allowed students to respond to questions in a similar manner to an expert in the field because they are better able to predict physical phenomena and analyze data collected from an experiment (30-31).

2.6 Labs in Active Learning

Typical lab instruction often involves many active learning strategies, including working in groups, consistent interaction with instructors, and hands-on learning. One study found that out of 51 students, 67% found that working in teams was a benefit of lab work (32). Laboratory work in small groups encourages and supports connections between concepts and a Newtonian view of introductory mechanics, often improving their problem solving abilities (33). Student learning is aided by upwards of 50% when labs consist of conceptual questions that are answered individually and then discussed with other students (34). In Figure 8, several methodologies of laboratory instruction were tested with 625 students across different disciplines at different universities. Methods A, B, and C correspond to a more traditional lab style, where the students are given sets of instructions and asked to perform the experiments in small groups. Methods D, E, and F all implement active learning concepts; lab assistants work with at most four students to
individualize the lab process, as well as work with them to design the experiment rather than
hand them a set procedure (35). The significant increase in the percentage of student successes
help tie in active learning goals and outcomes in a laboratory setting. Working in small groups
guided by instructors through the design and experimentation of labs encourages a student to
develop skills alongside their conceptual knowledge.

**Figure 8:** This graph shows that students succeeded the most when labs were conducted according to methodology E. This entailed a pretest before the experiment, which is prepared by lab assistants and students together. The students then work in pairs to complete the experiment and prepare a report about it, followed by a post-test. From Reference 35.

The RealTime Physics (RTP) curriculum was developed to align with goals for
introductory labs set forth by the American Association of Physics Teachers (36). These goals
include helping students gain an understanding of physics concepts, develop traditional
laboratory skills, and combine conceptual activities and quantitative experiments to better
understand material covered outside of the lab (29). **Figure 9** shows the differences in students’
demonstrated understanding of the natural language and graphical representations of dynamics
from before to after instruction using the RTP labs at the University of Oregon, alongside the
algebra-based introductory physics course. Before the RTP labs, the gains in student understanding were approximately 10%; on average, the percent of students understanding the material increased by nearly 70% in both natural language and graphical evaluations after the implementation of RTP labs. These significant increases demonstrate that active learning in a lab setting can significantly increase the number of students reached and improve their comprehension of the material, as well as help them develop basic lab skills (29).

![Figure 9: The increases in student understanding from pre- and post-implementation of the RealTime physics curriculum at the University of Oregon in algebra-based introductory physics. The left bars represent how well students understand the natural language descriptions of motion and forces. Those on the right show the students’ understanding of graphical representations of dynamics concepts. From Reference 29.]

### 2.7 Technology in Labs

In the past 20 years, technology has become an increasingly beneficial aspect of labs, starting with computers and rudimentary simulations (12, 14). Instead of rulers and stopwatches, probes and sensors are used to obtain more accurate and reliable data. A study conducted using an Apple Watch took advantage of the device’s software-based gravity sensor to help students visualize the forces acting on a block on an inclined plane, as seen in Figure 10. It accomplished this by placing the device in a cardboard box, and using an app to display a free body diagram (FBD). It is especially useful because rather than drawing several FBDs on a whiteboard for
different scenarios, all an instructor is required to do is change the angle of the incline, and the FBD on the display changes with it (37).

Experiments can also be recorded, then slowed down and analyzed by students to better understand the related concepts in physics. For example, a projectile motion lab can plot position against time, so students can relate a graph of motion to a real-life situation. These videos work because the human eye is programmed to follow motion, and a computer display can further emphasize the important aspects of the video (27). It also helps students practice interpreting graphs and understanding reference frames (38-39). One study used software to conduct virtual lab simulations, where data could still be obtained using virtual instruments, eliminating the need to buy lab equipment and the time spent setting up and taking down labs. This study also found that students who participated in virtual labs did just as well as their traditional counterparts (40). Another study went so far as to conduct these virtual labs by using a virtual reality (VR) apparatus like the HTC Vive so that students could still have a “hands-on” experience that is not possible using the computer simulation, as shown in Figure 11. They found that the VR
experience was much more engaging than just a virtual simulation on a normal computer, but it was more difficult for students to read and take notes while conducting the experiment. In the end, it is recommended to use the VR set-up for more exploratory and simple experiments (41). These are cheaper options in the long run, but a problem arises when schools might not have computers or a VR headset, or even be able to afford the required software and materials.

Figure 11: An example of a VR lab using a Van de Graaff Generator. This is a screenshot of what the student sees while wearing the HTC Vive headset. This configuration allows students to walk around a 3D space and interact with virtual objects. They can interact with experiment settings using the Vive controllers, and in this example, instantly visualize the electric field and see the induced electric current over time. From Reference 41.

2.8 Cost-effective Lab Materials

Students and teachers both agree that labs provide important learning benefits and opportunities for the students to gain important experimental skills. Despite this, common equipment used in introductory labs remains highly costly for the institution both in space and funds (22). Even though labs have been proven to be beneficial, the positive outcomes of providing the labs to the students may not be worth the high cost of the equipment. When considering whether to purchase expensive lab equipment, the institution must balance cost to the benefit of providing the lab (25). Unfortunately, some school districts may not be able to afford to purchase expensive traditional lab equipment at all. This leaves teachers unable to provide their students with helpful hands-on activities and demonstrations of real physical
phenomena (42). Students then lose the benefits of lab-based active learning, such as experimental skills, seeing physical concepts play out in real time rather than just from mathematical equations, and collaborating with other students on experiments. One solution to the problem is using virtual labs; this reduces the need for hands-on activities and therefore expensive traditional lab equipment. However, providing virtual labs can be a challenge for a low budget school if the institution is then unable to afford an adequate number of computers or the software necessary to run the virtual labs (40).

In recent years, cell phones have become more common as a means of implementing active learning in classrooms. One purpose of cell phones is answering questions during lecture, similar to the clicker system. There is free software, such as Socrative or Poll Everywhere, that can be used to present questions to students and collect answers. In addition, students can access and answer the questions from their own personal mobile device, so there is no cost for the institution to implement this system. Smartphones have become more prevalent; one study suggested that up to 98% of high school students in 2010 owned and carried a smartphone. Especially with the use of group work, it is almost guaranteed that each group will have at least one smartphone (21).

The use of smartphones in classrooms has increased recently as a tool for hands-on activities and labs and to model different physical scenarios (43). Smartphones are well equipped to be used in basic experiments, such as those commonly found in introductory physics labs. The user of a smartphone is much more familiar with the device than with traditional lab equipment and is more comfortable using its features. Modern day smartphones also contain a range of data collection methods, including a wide variety of sensors, a camera, and a notepad to store data.
One study indicated that the use of cell phones as experimental tools in labs raised the students’ interest levels in the lab and the material significantly. Furthermore, it was shown that using a cell phone during the lab was likely not a distraction for the students, despite this being a concern for many instructors considering bringing cell phones into their classroom (45). With these benefits, labs covering a wide variety of levels and topics have been developed using smartphones and other smart devices (37, 46-48). One example is using the magnetic field sensor in a smartphone to measure the magnetic fields of several types of magnets. By measuring the field at different distances from the sensor and graphing these points, students can obtain the relationship between the magnitude of the magnetic field and the distance from the magnet and compare their result with theory (48). These labs are not only beneficial to the students, but also a practical option for institutions that are looking to incorporate labs into their curriculum, as they require little to no funds if students can provide their own mobile devices.

2.9 Summary

High school students who want to pursue a higher degree in science are encouraged to take, at a minimum, common core biology, chemistry, and physics. Taking physics in high school, student GPA, and socio-economic status are factors that indicate a students’ likelihood of success in college physics (49). However, as we have seen, physics is a subject that is difficult to teach and difficult for students to learn, even without the added barriers of underqualified teachers and lack of funding (2, 4, 9, 12). The goal of our project is to combine these ideas — active learning, technology, and labs — to create cost-effective, hands-on lab modules that are easy to implement in secondary schools.
3. Methodology

This section will focus on how the authors designed the lab modules and how they collected data from other undergraduates regarding the effectiveness of the labs. Due to administrative constraints, the project team was unable to perform trial runs with the target demographic; proposals and important administrative requirements are listed in Appendix A for reference for potential future project work.

3.1 Lab Design

The authors spent an academic term assisting the instruction of the general mechanics course in a studio setting, which included two hands-on activities per week. This course utilized several different aspects of active learning, specifically:

- mini-lectures, designed to be a shortened adaptation of traditional lectures;
- clicker questions, utilizing an individual response system to gauge real-time understanding;
- hands-on activities, such as the labs the authors designed for this project;
- challenge problems, which extend the applications of the concepts touched on in class to more complex examples that are solved by the instructor;
- and problem solving in a group setting, utilizing mobile whiteboards to encourage collaboration and increase understanding.

In Figure 12, the students’ responses to Likert-style questions at the midpoint of the term are shown. They rated each of the above aspects of the course on how helpful they found it; these results show that overall, the students believed the hands-on activities were helpful. In the space provided for candid commentary, the students expressed a need for a “debrief” of the hands-on
activities in the next meeting, which was worked into the course upon review by Professor Burnham. With confirmation that the hands-on activities were helpful, they were used as a guide for the authors to create lab modules that had similar structures and goals. Alongside Professor Burnham, the authors were able to gain first-hand insight into the students’ experiences with this studio style course. This course was run in two sections of approximately 72 students each, nearly all of which were first-year college students; this is not the exact target demographic for this project’s work. However, because many of these students were taking this class during their first academic term at WPI, the authors can use this course and its resultant data as a rough guide to use when researching and creating the lab modules for high school usage.

![Helpfulness of main studio activities graph](image)

*Figure 12: This graph shows the responses at the midterm point in the studio mechanics course run by the authors and Professor Burnham. The survey asked the students to answer Likert-style questions on the helpfulness of the mini-lectures, clicker questions, hands-on activities, challenging problems, and group problem-solving.*

### 3.1.1 The Impact of the MBT

The Mechanics Baseline Test (MBT) was administered to the students of the introductory mechanics course at the beginning and end of the course as a way to gauge their progress using a
vetted examination process (50). Students in sections 1-3 of the class had an average score of 10 ± 4 at the beginning of the course and an average score of 13 ± 4 at the end. Students in sections 4-6 of the class had an average score of 11 ± 4 at the beginning of the course and an average score of 14 ± 4 at the end. The overall improvement in scores after completion of the course suggests that the studio course successfully increased the students’ performance and conceptual knowledge in mechanics. The students’ exam score changes influenced the authors’ determination of conceptual areas that required more attention and might be improved with redesigned labs. These collected data, as well as several studies previously done on this topic, gave the inspiration for the authors’ initial labs and their tailoring to fit a high school curriculum.

3.1.1. Questions on Friction

Question 7 of the MBT (shown in Figure 13) concerns a block being pulled at a constant speed by a force $F$ opposed by friction given by $k$. It asks students to select the relationship between forces $F$ and $k$ and between $N$ and $W$. This was the only question that decreased in the number of students that selected the correct answer; 42% of students chose the correct answer for the pre-test, but only 34% chose that same answer for the post-test, as shown in Figure 14.
7. A person pulls a block across a rough horizontal surface at a constant speed by applying a force $F$. The arrows in the diagram below correctly indicate the directions, but not necessarily the magnitudes of the various forces on the block. Which of the following relations among the force magnitudes $W, k, N,$ and $F$ must be true?

\[
\begin{align*}
\text{(a) } & F = k \quad \text{and} \quad N = W \\
\text{(b) } & F = k \quad \text{and} \quad N > W \\
\text{(c) } & F > k \quad \text{and} \quad N < W \\
\text{(d) } & F < k \quad \text{and} \quad N = W \\
\text{(e) } & \text{None of the above choices}
\end{align*}
\]

Figure 13: Question 7 from the MBT, depicting forces $W, N, F$ and $k$ acting on a block travelling along a rough surface at a constant speed.

Figure 14: A comparison of student performance on Question 7 of the MBT at the beginning and end of the course. The correct response is represented by a green bar, while incorrect and blank responses are represented by orange bars.

Question 9 (shown in Figure 15) asks student to approximate the maximum speed of a metal cylinder held on a turntable by static friction as it is rotating. In the pre-test, 24% of students chose the correct answer, whereas 30% of students chose that same answer for the post-test, as
shown in Figure 16. Because of the minimal and negative change in performance on these questions, a friction lab module was developed to further enforce its concepts.

Figure 15: Question 9 of the MBT, depicting a metal cylinder on a rotating turntable held on by friction.

![Figure 15](image15)

Figure 16: A comparison of student performance on Question 9 of the MBT at the beginning and end of the course. The correct response is represented by a green bar, while incorrect and blank responses are represented by orange bars.

![Figure 16](image16)

3.1.1.B Questions on Conservation of Energy

Question 10 (shown in Figure 17) asks students to choose which slide will give a young girl the greatest speed after sliding down. The young girl will start and end at the same respective heights with each slide. In the pre-test, 47% of students chose the correct answer, whereas 79% of students chose that same answer for the post-test, as shown in Figure 18.
Question 10. A young girl wishes to select one of the frictionless playground slides illustrated below to give her the greatest possible speed when she reaches the bottom of the slide.

Which of the slides illustrated in the diagram above should she choose?

1. Slide 1
2. Slide 2
3. Slide 3
4. Slide 4
5. It doesn’t matter, her speed would be the same for each slide.

Figure 17: Question 10 from the MBT, depicting a young girl at the top of several slides of different shapes.

Figure 18: A comparison of student performance on Question 10 of the MBT at the beginning and end of the course. The correct response is represented by a green bar, while incorrect and blank responses are represented by orange bars.

Question 11 (shown in Figure 19) asks students to determine the boy’s speed at point Q, the lowest point in his swing. The students are given a length of the swing, the boy’s mass, and the starting height of the swing. In the pre-test, 13% of students chose the correct answer, whereas 30% of students chose that same answer for the post-test, as shown in Figure 20. Because of the
minimal, but positive, change in performance on these questions, a conservation of energy lab module was developed to continue enforcing its concepts.

\[ P \text{ and } R \text{ mark the highest and } Q \text{ the lowest positions of a } 50.0\text{-kg boy swinging as illustrated in the following figure.} \]

![Figure 19: Question 11 from the MBT, depicting a boy on a swing.](image)

11. What is the boy’s speed at point Q?
   1. 2.5 m/s
   2. 7.5 m/s
   3. 10.0 m/s
   4. 12.5 m/s
   5. None of the above.

*Figure 19: Question 11 from the MBT, depicting a boy on a swing.*

![Figure 20: A comparison of student performance on Question 11 of the MBT at the beginning and end of the course. The correct response is represented by a green bar, while incorrect and blank responses are represented by orange bars.](image)

*Figure 20: A comparison of student performance on Question 11 of the MBT at the beginning and end of the course. The correct response is represented by a green bar, while incorrect and blank responses are represented by orange bars.*
3.2 Collaboration with WPI SPS

For this project, the authors collaborated with the WPI chapter of the Society of Physics Students (SPS) to test the lab kits. SPS consists of physics students of various backgrounds and levels, and most have gone through the introductory series of physics classes at WPI, including a lab component. During a general body meeting, the authors brought in their lab modules to present, and the members worked through the activities and worksheets. This was not the demographic that the authors had intended to target, but the added constructive criticism from peers helped to improve the overall quality of the labs. Along with general comments, a survey was distributed to obtain quantitative feedback (Appendix B).
4. Description of Lab Modules

The goal of this project was to design lab activities which a future project team could then test and suggest to high schools. Each lab activity conveys learning objectives for a specific topic (friction, conservation of energy, and torque), is cost-effective, and promotes active learning methodologies in classrooms without a formal lab report. While conducting each module, it is intended that students will work in small groups, and instructors will walk around the classroom to answer any questions that the students may have. Descriptions of each designed lab module will be discussed in this section.

4.1 Friction Lab

Friction is a universal concept which is present in any realistic scenario that students work with, but many labs instruct the students to ignore friction and air resistance and assume an ideal environment. From their experience as Peer Learning Assistants (PLAs) for a course in introductory mechanics, the authors witnessed students struggle with several fundamental concepts of static and kinetic friction. The concepts that the students struggled with the most were used to develop a set of learning objectives for a lab focused on friction. These learning objectives include

- Calculate the predicted acceleration of block down a slope with a given angle.
- Describe the differences between static and kinetic friction.
- Describe the direction in which friction acts and how it affects motion.
- Calculate the coefficient of kinetic friction based on the force of friction and the normal force on the block.
A worksheet including a small set of questions was designed alongside the lab, with the questions structured to focus on the learning objectives; the goal of the questions is to aid the students in considering difficult and fundamental concepts while they perform the activity. The full set of learning objectives, as well as the questions from the worksheet, can be found in the Teacher’s Manual in Appendix C.

Because friction labs are uncommon compared to labs concerning topics such as basic kinematics, force, and torque, it was difficult to get inspiration in designing the lab from past experiences. Furthermore, most introductory lab equipment, such as cars and pulleys, is designed to eliminate the effects of friction as much as possible. The authors focused on a block and ramp set-up, such as in Figure 21, due to its simplicity in designing the equipment. A ramp is basic enough that the authors were flexible in choosing a material for it. Flexibility in choosing materials allowed the authors to focus on minimizing the cost of the equipment, a critical goal for the project. The block-on-a-ramp scenario also leads to ease of solving for the coefficient of friction using very few measurements. The force diagram contains three different forces, which all act in only two of the three spatial dimensions. With the relationship between the forces, the mass of the block cancels out of the equations, which means that the instructor does not need to carefully mass the blocks to ensure that students can get accurate results.
Figure 21: A basic diagram of the block and ramp set-up used in the friction lab module. The values on the diagram, $d$ and $\theta$, are values used in the worksheet to calculate the coefficient of static friction.

The authors decided that the most suitable material for the ramp is corrugated cardboard because it is flexible enough to be bent into the shape needed for a ramp, but firm enough that it does not bow beneath the weight of the block. New sheets of cardboard or cardboard boxes can be purchased for a low cost, and scrap cardboard can be collected for free from delivery boxes and recycling bins. The block should be approximately 4 inches by 4 inches in length and width, but the material can vary. The only other material included in the lab equipment is a ruler to measure the length of the ramp. A student’s personal smartphone can be used to measure the angle of elevation of the ramp and the time it takes for the block to descend the ramp.

To perform the lab, the students first find an angle of elevation for the ramp that is great enough that the block is just able to slide down. After setting up the ramp, the students answer a conceptual question related to static friction to better understand how differing angles of elevation affect the motion of the block. The students then use a smartphone to measure the angle of elevation of the ramp and use that angle to determine the predicted acceleration of the block down the ramp. The students place the block on the ramp and use the ruler to measure the
distance from the bottom of the ramp to the block. They then use the smartphone as a stopwatch to record how long it takes for the block to descend to the bottom of the ramp, and use the distance and time to determine the actual acceleration of the block down the ramp. The students answer a conceptual question about friction acting in the direction opposite the motion of the block, and then finally calculate the coefficient of kinetic friction between the ramp and the block. The final conceptual question asks the students to make connections between the angle of elevation of the ramp and the normal force on the block, predicted acceleration of the block down the ramp, and the coefficient of kinetic friction. The worksheet, which includes the full protocol, is available in Appendix C. The Teacher’s Manual, available in Appendix C, includes the learning objectives, materials, a guide to building the ramp, the protocol, and the conceptual questions and answers.

4.2 Conservation of Energy Lab

The idea that energy cannot be created or destroyed is fundamental to the way we understand Newtonian mechanics. The topic of conservation of energy is often taught as a large section of an introductory mechanics course, covering the different types of mechanical energy and how it is transformed and transferred through objects in motion. This topic is often crucial in the understanding of systems of multiple objects and how they move and interact with one another. Throughout the authors’ time as PLAs, it has been observed that students often have difficulties in interpreting questions into equations and understanding the transformation of energy from one type into another.

This lab was inspired by a visual representation of mechanical energy. A vertical spring-block system shows the force of gravity working in tandem with the restoring force from
the spring, offering a tangible transformation of energy from gravitational potential to elastic potential to kinetic energy. At the conclusion of this lab, students should be able to

- Describe how energy is conserved in an ideal system.
- Describe how energy is transferred to different forms as an object moves.
- Identify the types of mechanical energy present in an oscillating system.

This lab can easily be done using a sensor system compatible with softwares such as LoggerPro or PASCO Capstone and the use of a computer setup. These options for data collection, however, are often expensive and often are out of reach for school districts with a smaller budget or too few computers for the number of students in a class. The proposed lab is designed to produce similar data collection ideas with a significant decrease in price and increase in accessibility. Springs, of approximately 30 N/m, can be purchased in bulk to anticipate any wear and tear, specifically stretching and loosening. Paperclips are a very basic office supply that can be used as fasteners, alongside washers, which can take the place of expensive mass sets, and meter-sticks, a simple but effective classroom staple. Small dowels and clamps can be purchased inexpensively from various hardware stores, which allows for students to hang things from the edge of a desk or table.

The students will be given a worksheet to complete at the end of the session. They will start by clamping the dowel to the edge of a table or desk such that a small portion sticks out over the edge. Hang one paper clip on the dowel between its end and the table or desk. Attach the spring to the hanging paperclip. Attach another paperclip to the bottom end of the spring. From the bottom paperclip, hang 15 washers. Stand the meter stick so it is vertical next to the system. Pull the washer-spring system so that the spring stretches 10 cm. Use a smartphone to
record one full cycle (from release to the next time the washers are at their lowest point) using slow motion. Use a smartphone stopwatch or manual stopwatch in the video to record the timing of the system. A simplified schematic of the washer-spring system is shown in Figure 22.

![Figure 22: A basic schematic of the washer-spring system in the conservation of energy lab module.](image)

Seen in Appendix D, the students take the information from the video and the given spring constant, displacement, and constants to find the approximate maximum velocity of the washers. They are also asked to classify the energy of the system at different points in its oscillation, checking their understanding of the types of mechanical energy and how the cycle of position relates to the cycle of energies present. The worksheet, which includes the full protocol, is available in Appendix D. The Teacher’s Manual, available in Appendix D, includes the learning objectives, materials, the protocol, and the conceptual questions and answers.

### 4.3 Torque Lab

Throughout the background research conducted for the literature review chapter, there was never a study that included rotational motion or torque, and throughout the authors’ time as PLAs, this was an area that students struggled with the most. Some of them seemed to draw analogies between linear motion, but most, if not all, had trouble setting up a torque balance and
solving it. Also through conversations with past teachers and professors, the authors asked what instructors thought students tend to have problems with, and torque was agreed upon by all the authors had talked to. While conducting the torque lab activity as PLAs, the authors observed that students had trouble relating the equation for torque to a graph of experimental data, specifically how changing distance and the angle between the force and the object contributed to the magnitude of torque. The learning objectives include

- Describe why torque is kept constant throughout the activity.
- Graph force vs. distance and force vs. angle.
- Solve for force \( F \) using the formula for torque \( \tau = F \sin \theta \).
- Show that \( F \) is proportional to \( 1/l \) with constant angle.
- Show that \( F \) is proportional to \( 1/\sin \theta \) with constant distance.

In designing this lab, the core experiment is the same as was for the studio physics class; a pencil acting as a fulcrum with a ruler balanced on top, with torque being kept constant, and students balancing the ruler at different distances and angles with a spring scale. The main changes were that instead of a mass set, there was a stack of washers taped together to act as a weight, to make the set-up more cost-effective, and changes that were made to the worksheet that accompanied the activity. More specifically, an introduction paragraph with background information about torque to refresh what students may have already learned in lecture, or to teach them the basics of what they needed to complete the lab.

Along with a pencil, ruler, washers, and spring scale, the lab included masking tape and the student’s phone to act as a protractor, using the same applications as for the friction activity. The pencil is taped to be parallel to the edge of a table, and the ruler is taped perpendicular to the
pencil in a way that it can still pivot. The washers are taped to the end of the ruler that is on the table, so that the other end can be used to take measurements. A simple diagram of the lab set-up is shown in Figure 23.

![Figure 23: A simple diagram of the torque lab set-up.](image)

$r$ and \( \theta \) represent the distance to the force and the angle that the force acts in.

After the activity is set-up (approximately 5 min), students will attach the spring scale perpendicular to the ruler at five different distances and record the force required to keep the ruler level. Then attach the spring scale to the ruler with tape, and record the force required to keep the ruler level at 5 different angles (two less than 90, 90, and two greater than 90). After collecting data, students will be asked a series of questions to walk them through isolating force from the formula for torque, and be asked to graph the data (distance vs. force and angle vs. force). Ideally this will help students understand the relationship between torque and distance and torque and angle. The accompanying worksheet and teacher’s manual, including the full protocol, conceptual questions, learning objectives, and materials are available in Appendix E.
5. Results

This section discusses the results of the surveys for each of the three designed lab modules from the event held by WPI’s chapter of the Society of Physics Students (SPS). The organization’s members rated several statements about the labs 1-5 on the Likert Scale, with 1 being that the member strongly disagreed with the statement and 5 being that the member strongly agreed with the statement. The official survey used at the event is in Appendix B, and the statements from the survey are listed below for convenience.

1. The lab demonstrated physical concepts well.
2. The lab worksheet connected the physical concepts to equations well.
3. I feel that this lab will help students new to physics understand these concepts.
4. I feel that a lab similar to this style could be beneficial to students’ learning in other physical concepts.
5. I feel that this lab will encourage students to communicate with their classmates and/or their instructor(s).
6. I feel that the lab was clear, concise, and easy to follow.

5.1 Friction

Eight members of the WPI chapter of SPS tested and turned in a survey for the friction lab module, all of whom had taken an introductory mechanics course and an accompanying lab section at WPI. Of these eight members, three were first year students, four were seniors, and one did not report a class year. Furthermore, four out of these eight members also had experience with being a peer learning instructor for an introductory mechanics course or lab section at WPI.
Figure 24 shows an image of one of the members measuring the distance between the bottom of a cardboard ramp and a soap dish block filled with marbles. As they worked with the lab and worksheet, the members were encouraged to leave comments and suggestions on a copy of the worksheet. A scanned copy of the marked worksheet can be found in Appendix C. A majority of the comments were suggestions to improve the clarity of the instructions and questions on the worksheet. Several other comments brought attention to typing mistakes, while others made suggestions to add equations or explanations to different steps of the protocol for the lab.

The friction lab module received strictly positive ratings (greater than 3), with the average rating for each statement being greater than 4.0. The members of SPS agreed most strongly that labs with a similar style could aid students learning other concepts, giving the
statement an average rating of $4.7 \pm 0.5$; 5 out of the 7 people who answered this question strongly agreed with the statement. Those surveyed also believed that the lab demonstrated physical concepts well, giving an average rating of $4.6 \pm 0.7$. The survey stated that the lab would help students who were new to physics learn the concepts well with a rating of $4.5 \pm 0.8$. The next highest rating stated that the lab was clear and easy to follow, with an average rating of $4.4 \pm 0.5$. The members somewhat agreed that the lab connected the concepts to the equations well, giving the statement a rating of $4.1 \pm 0.6$. Finally, the statement with the lowest rating was that the lab would encourage students to communicate with their classmates and instructor, earning an average rating of $4.0 \pm 0.8$. The average ratings of each statement for the friction module are summarized in Figure 25, and scanned copies of each survey can be found in Appendix C.

![Figure 25: Average ratings and standard deviation for the friction lab module from the surveys given to WPI SPS. Statement numbers correlate to the order in which each statement appeared on the survey given to the members (Appendix B).](image)

Along with the statements, the survey included a section for the members of SPS to write comments or suggestions for the lab set up or worksheet. The most common suggestion was to improve or expand upon the equations used in the worksheet, such as calculating the static
friction force, using the actual equation for force of friction, and further explaining the equations. The second most common suggestion was to improve the writing of the worksheet and make the instructions of the lab more clear. One member also suggested either having a free body diagram available on the worksheet, or having a question on the worksheet be to draw the free body diagram for the situation. The final suggestion was to have different materials available for the students to try to see how the coefficient of friction is dependent upon the materials used. All suggestions can be found on the marked worksheet and surveys in Appendix C.

5.2 Conservation of Energy

The conservation of energy activity was tested by six members of the WPI chapter of SPS; all of these students had at this time taken the introductory mechanics course and the accompanying lab component. Three students were first-year students, and three were seniors. All seniors that surveyed this lab activity had previously acted as peer learning instructors for the WPI introductory mechanics course.

Figure 26 shows two students during the activity, taking a slow-motion video of the washers on the end of a spring as they oscillate. Copies of the worksheet were provided to solicit feedback from the students on several aspects of the activity and its efficacy; this commentary is provided on the document in Appendix D. A significant number of suggestions focused around clarity and specificity in the instructions. A few students suggested including a diagram to be sure the procedure is followed clearly. Several other comments were made about the depth this activity covered in comparison to the other two, as well as the expressed desire for more conceptual questions to be added.
The conservation of energy activity received overall positive ratings with several negative ratings dispersed throughout the survey results. The students mostly agreed that this lab will help students without a significant background in physics understand concepts, giving this statement an average rating of $4.1 \pm 0.9$. They also agreed that labs of a similar style could be beneficial in supplementing the learning of other physical concepts; this statement received an average rating of $4.0 \pm 1.2$. With an overall rating of $4.0 \pm 1.0$, students mostly agreed that this lab will encourage students to communicate with their classmates and/or their instructor(s). They somewhat agreed that the lab was clear, easy to follow, and concise, giving that statement an average rating of $3.5 \pm 1.3$. The students only mildly agreed that this lab demonstrated physical concepts well, receiving the lowest average rating of $3.0 \pm 1.4$. Figure 27 summarizes the data from the conservation of energy lab module; completed surveys can be found in Appendix D.
The members of SPS were encouraged to leave comments about the set up for the activity and accompanying worksheet. Several comments were small grammar and capitalization errors. One student mentioned that the addition of learning objectives to the lab worksheet may be of benefit to the students. A majority of the feedback, however, mentioned that the instructions were unclear, and many students mentioned the desire for a diagram to ensure the procedure be followed correctly. One student recommended being explicit in describing the video-taking procedure, such as when to start the timer in frame. Multiple students mentioned being more specific in the calculations in the second question, being sure that the students can find the instantaneous velocity at the system’s center of oscillation. Two students mentioned that the lab needs more in-depth, conceptual questions to make potential students think about and explain how energy functions. Overall, this activity needs improvement in clarity, instruction, and depth in conceptual questions.
5.3 Torque

Six members of SPS surveyed the torque activity, all of which had taken WPI’s introductory mechanics class. They consisted of three seniors (who have all PLA’d an introductory mechanics class), three freshmen, and one who did not specify. Figure 28 is a picture of two students measuring the force required to keep the ruler level.

Figure 28: Two students working through the torque activity, measuring the force required to keep the ruler level.

According to the survey, the participants most strongly agreed that this lab will help students new to physics understand these concepts (4.8 ± 0.4), 5 out of 6 who “strongly agreed.” The second highest level of agreement was tied between how well this style of lab could be beneficial to students in other areas of physics (4.6 ± 0.5), and how well the lab demonstrated physical concepts (4.6 ± 0.5). The participants also rated how well the lab will encourage student-student and student-instructor conversation with a level of agreement of 4.3 ± 0.5,
suggesting that more “why?” or conceptual questions could be used for sparking conversation. They rated how well the worksheet connected the physical concepts to equations a $4.0 \pm 0.8$, and the clarity of the worksheet was rated the lowest at $3.4 \pm 0.9$. All of these data are shown in Figure 29, and scanned copies of the surveys can be found in Appendix E.

![Figure 29: Average ratings and standard deviation for the torque lab module from the surveys given to WPI SPS. Statement numbers correlate to the order in which each statement appeared on the survey given to the members (Appendix B).](image)

More qualitative data was obtained with the surveys as well as suggestions written on physical copies of the lab worksheet, to help improve the lab for the future. Many people suggested to include diagrams of the set up, and to be more specific with instructions. They also said that some of the questions were confusing, and might not lead the students to the correct equation by the end. However, most participants supported the graph questions; one in particular said, “I like the graphing portion… great idea.” By far the biggest problems with the lab were several formatting issues and that the erasers were not heavy enough to produce the correct data. All surveys and marked up worksheets can be found in Appendix E.
5.4 Overall

There were several suggestions that were given to all three of the lab modules. One suggestion was to include a simple, schematic diagram of the lab set-up on the worksheet for the students to refer to. Another common suggestion was to expand on the equations used on the worksheets by including a wider variety of equations and by further describing how the equations are derived and used for the relevant concept. Many members of SPS also suggested improvements to the instructions to resolve ambiguity in measurements and grammatical mistakes in order to make the instructions more clear overall.
6. Discussion

In this section, the authors will discuss their thoughts on the original plan for the project and how the team failed complete their original goals. The authors will also further discuss the results from the event with WPI’s chapter of the Society of Physics Students (SPS) and the revisions made to the lab modules.

6.1 Original Plan

The original plan for this project was to test these lab modules in Worcester Public Schools (WPS), such as Worcester Technical High School (WTHS). The authors had planned to go into the classroom over several weeks towards the end of WPI’s B-term (end of November/beginning of December), evaluating one lab module each time and surveying the students. However, during this time, WPS was transitioning to a new system which required completing more forms in order to perform research in the classrooms. This was frustrating because of the shortened timeline caused by WPI’s term-based schedule, and in order to comply with the new forms, the authors would not be able to go into the classroom until the middle of C-term (February). Because the project terminated at the end of C-term, this was not a practical plan for completing the IQP report on time.

Due to these obstacles, the authors decided to take the project in a different direction and help a future group of students be able to go into a high school classroom setting. The lab kits were still tested with the WPI chapter of SPS, and the authors received constructive feedback on how to improve them.
6.2 SPS Results

This section will further discuss the results from the event put on by the WPI chapter of SPS. The authors will discuss implications from the results for the ratings on the survey, as well as from the comments left on the bottom of the survey and on the worksheets. This discussion will includes changes made to the lab set up or the accompanying worksheet and how the lab could influence future work.

6.2.1 Friction Results

The friction lab module received strictly positive results on the survey during the SPS event, with the average rating for each statement being a 4.0 or above, suggesting it has strong potential to be beneficial to high school students. The members who completed the survey most strongly agreed that labs of similar style to the friction lab module could aid students in learning other concepts. The lab was designed so that the set up was simple, which ensured that the equations used in the worksheet stayed as simple as possible as well; then the main focus of the worksheet and protocol could be on the concepts. The statement that members agreed the least with is that the lab stimulated discussion among the students and between students and the instructor. Research done for the literature review revealed that student learning can increase as much as 50% when students discuss the concepts with their peers (34); therefore, altering the worksheet to further engage discussion was important to further benefit students.

The comments and suggestions written on the worksheet and the bottom of the survey given to the members were also used in altering the lab module. One of the most common suggestions, besides simple typing errors, was to improve the clarity of the instructions and questions. Clarifications for instructions were accepted to avoid ambiguity and included in a
revised version of the worksheet. A suggestion to include a variety of other materials to also calculate the coefficients of friction for was also considered but ultimately not included to ensure that the lab stayed brief. A final comment suggested including a free body diagram on the worksheet or having the students create one themselves so that they could better understand how equations for different values were derived.

Ultimately, the set up for the friction lab module was not changed in any way. This kept the equipment and calculations as simple as possible, and allowed for the lab to stay within a 20 minute completion time. However, several changes were made to the accompanying worksheet. Typing errors were corrected, and edits were made to ensure that the instructions were clear and could not be interpreted in a way that could lead to misleading results. The final question on the worksheet, originally asking about how increasing the angle of elevation affected the normal force, acceleration of the block, and coefficient of kinetic friction, was replaced to include a question where students draw a free body diagram of the lab set up and discuss the forces that arise. All completed surveys, as well as the marked original worksheet, are included in Appendix C, along with a final version of the worksheet.

6.2.2 Conservation of Energy Results

The lab module concerning conservation of energy received mostly positive ratings with each statement receiving an average greater than 3.0 from the surveyed SPS members. Clarity of instructions and visualizing the set up presented themselves as issues when reviewing the responses; this supports the continued development of the lab module such that it can be as beneficial as possible to the learning of students. Little of the feedback questioned the necessity of a lab module based in energy conservation, which helps solidify its use in a future project.
Overall, the accompanying worksheet was the largest source of criticism for this lab module. Most of the students mentioned it lacked the same depth as the others, and gave minimal explanation of the concepts and equations. This encouraged a change to the questions asked; instead of writing equations into a table, the students can be asked to label a diagram with given equations of energy. This can ensure that the lab is being executed correctly, as well as visualize the presence of different types of mechanical energy directly in the system they are observing.

The concern with creating a lab in conservation of energy is that it is nearly impossible to create a system that will not lose energy due to friction, a damped oscillation, imperfections in springs, and various other causes. At first, a full calculation of total energy was avoided to save both time and possible confusion in the numerical values that might not show that energy is conserved.

Because this lab module is meant to be inexpensive, the use of smartphone cameras is involved to act in a similar way to a sensor. This does present some possible error in calculation as all numerical answers depend on the measurements made by a human eye; while a good substitute for expensive lab equipment, this method, without highly specified direction, can lead to unrealistic calculations. The worksheet originally posed a question to use information from the video and find the velocity of the oscillation about its center. This question can be changed to use equations rather than calculating an average speed at the center with information directly from the video. Improved clarity in directions and a more concise and descriptive flow of the worksheet can greatly improve the potential of this lab module, as well as help students extend their knowledge of conservation of energy past equations into a visual form. All completed surveys, as well as the marked original worksheet, are included in Appendix D, along with a final version of the worksheet.
6.2.3 Torque Results

The torque lab received positive results, the most positive being that a lab similar to this style could help students learn, which supports the goal of creating an active learning experience. The most common suggestion from the surveys was to make the directions clearer and to add diagrams. There was some confusion about the specific orientation of the ruler-pencil system, and which direction the dynamometer should be pulled. However, in an effort to keep the worksheet on one page, a teacher’s manual could be added, with the learning objectives of the lab module, more detailed instructions, what diagrams to draw on a class whiteboard, and the answers to the worksheet questions.

Another comment was to add more conceptual questions to spark more conversation between students. As stated in section 6.2.1, peer-to-peer communication can greatly improve student performance, further supporting the motive to revise this aspect of the lab. This could be done using more qualitative questions or instructions to compare results with other groups nearby. Perhaps an introductory ice-breaker activity could be added to the teacher manual as well, where students are told to open a door various ways to experience how the force they apply on the door increases or decreases when changing the distance from the hinge or angle from the door. All completed surveys, as well as the marked original worksheet, are included in Appendix E, along with a final version of the worksheet.

6.2.4 Summary of Results

There were several general suggestions from the SPS event which applied to all three of the lab modules. For instance, it was suggested that the worksheet for each lab include a diagram, such as Figure 30, of the set up; this would allow students to write down any relevant
information or equations for the lab, such as creating a free body diagram by writing down the forces acting on the set up. Many of the participants also suggested to make the use of relevant equations more detailed. The main purpose of the lab activities is to aid the students in making connections between the mathematical equations and the physical concepts, and so it is important that the students know which equations are relevant to the concept, where each equation comes from in the set up, and how the equations are used in calculating results for the lab. This can be done by either asking the student to provide the connection in a question or by supplying it to them with a brief description or a diagram. Other common suggestions were to improve the clarity of the instructions; a lot of the participants which made comments on the worksheet made note of where the instructions may be ambiguous.

![Diagram](image)

*Figure 30: The black triangle and box show a potential diagram that could be included in the worksheet for the friction lab module. The blue writing shows examples of how a student may write notes about the forces and values associated with the lab.*

The authors used these suggestions and comments to improve the worksheets and lab set ups. Many of the suggestions which involved clarifying instructions were incorporated into revised versions of the worksheets. Other suggestions, such as including diagrams, different
equations, and explanations, were considered for each worksheet individually, as the authors wanted to keep the worksheets concise. Revised worksheets, teacher manuals, original worksheets, and scanned copies of surveys and suggestions for each lab module are included in Appendices C-E.
7. Conclusions and Future Work

This section will discuss how the authors completed their original goals and where they fell short. A suggested plan for a future project team to expand off of the work done in this project is also discussed.

7.1 Conclusions

Overall, this project identified a gap in pedagogical research concerning the intersection of active learning, laboratory activities, and the accessibility of lab equipment. The authors used existing research and their experience as co-instructors in an introductory mechanics studio class to design inexpensive lab modules. Despite their original intent to gather feedback from high school students, several timing and bureaucratic complications prevented trials with the target audience. The WPI chapter of the Society of Physics Students (SPS) was used as a quasi-comparable population to collect data via surveys and comments to improve the original lab modules. These results were compiled into a poster, seen in Appendix F, for presentation at the 2019 March Meeting of the American Physical Society.

The main tenet of the lab modules was to involve active-learning strategies in lab work using inexpensive materials; the authors were successful in maintaining this throughout, and would use these ideas as a guide for future research. These labs use small groups to encourage and support the connections between concepts and a Newtonian view of introductory mechanics, as well as target conceptual questions that allow the students to extend their knowledge past that of equations alone (33, 34). The feedback received from SPS agreed that these labs, with some work, could accomplish these goals.
7.1.1 Limitations

This project has several limiting factors that prevented the authors from reaching their original goals and filling a larger portion of the existing research gap. It is difficult to generalize the results collected through this research; gathering data that can apply to a majority of students and classroom settings is highly improbable with six to eight survey results per lab module. Furthermore, the lack of target audience input limits this study. It is infeasible to apply strictly the information from this project to a high school classroom because the authors could not conduct this research with high school students, and therefore have minimal reference as to the performance of these modules in such a setting. Another limitation takes shape in the need to keep the modules brief, with an accompanying worksheet of no more than one page, and a maximum time of thirty minutes. This allows the authors to go in depth to a certain extent, but lacks the ability to stretch much further than conceptual questions, equations, and problem solving. These labs are not designed to stand alone, and are meant to fit within an existing curriculum, only to supplement students’ learning and conceptual understanding.

7.1.2 Summary

The authors’ end goal was to design three modular and inexpensive labs to supplement the learning of high school students in physics courses. Despite not reaching its full potential, the project team did create three lab modules and evaluated them, as well as created a detailed appendix (Appendix A) to provide guidance to a future project to extend this work.

7.2 Future Work

In this section, the authors intend to impart any wisdom or advice for those who may continue this project. The utmost important aspect of a future project would be continued testing
in a high school environment. The largest limitation that this project team faced was a timeline that was inconsistent with fulfilling administrative requirements for performing research in Worcester Public Schools. This section will outline a process for a future group to overcome this limitation and execute as many rounds of testing as possible given the timeframe. In the procedure outlined in Appendix A, the authors suggested allotting two academic terms at WPI, approximately 15 weeks, for testing and result compilation. An additional extension of this work could include the possibility of suggesting these lab modules to high schools to supplement an existing physics curriculum.

Originally, the authors’ goal was to evaluate the hands-on activities used in the introductory mechanics studio course, which they co-instructed with Professor Nancy A. Burnham at WPI, to look for successes and shortcomings. This experience was used to design lab modules such that they better reflected the needs of high school physics curricula. The authors intended to work with educators in Worcester Public Schools such that the modules could be tested by students directly in our target audience. The first meeting with Ms. Jocelyn Coughlin, the head of the physics department at Worcester Technical High School, occurred in mid-October; this was at the beginning of WPI’s second academic term, one-third through the allotted time for the project. This timing made it impossible for the project team to meet bureaucratic deadlines and prevented the test of these modules with high school students.

Appendix A is a suggested guide for a project with similar goals, and gives a detailed timeline to proceed and hopefully avoid the circumstances the authors arrived at. It is recommended to start communicating with Worcester Public Schools in September to allow ample time for the paperwork to be completed and approved or resubmitted if necessary. The
outline advises to have all paperwork approved and experimental sessions scheduled by the end of WPI’s A term in mid-October to be able to start testing the lab modules in November. This will also allow for multiple trials to be run with different groups of students, or repeated trials with improvements made to the modules in between.
References


Appendix A - References for Future Project Work

This appendix is designed to be used as a reference for a future project building off of the work done by the current team. A proposed goal and timeline for future work will be discussed, and important contacts, paperwork, and other reference materials will be listed for the convenience of the team which undertakes a future project.

A.1 Proposed Goal for Future Work

The current project focused primarily on designing the lab modules to be efficient and cost-effective; however, administrative constraints prevented the authors from performing trial runs of the labs with the target demographic. The current team proposes that future work focus on ensuring that the lab modules fulfill the goals of being efficient and easy to understand and implement in high school classrooms. This may include tasks such as, but not limited to:

- Perform trial runs of the labs with high school students.
- Collect data about how the students perform and interact with the lab.
- Analyze data to determine how the lab modules can be improved.
- Revise the lab modules according to data collected from students.
- Suggest the completed lab modules to prospective high schools to be implemented in their classrooms.

Figure 1 illustrates a simplified visual of the relationship between the current project and a future project, as well as the basic goals for future work.
A flowchart demonstrating the process used to design lab modules. Part A, initial design, was accomplished by the authors, and Part B is to be completed by a future project team.

A.2 Proposed Timeline of Future Project

This timeline is skeletal and provides a proposed schedule for important administrative deadlines and trial runs only. This timeline, furthermore, assumes that a future project would be conducted over 3 academic terms at WPI.

During the first term of the project, the project team should focus on contacting physics teachers at local public schools and fulfilling administrative requirements, such as IRB forms and CORI checks. Because processing can take varying amounts of time, forms should be submitted as soon into the term as reasonable; this allows for adequate time for the forms to be processing and allows for some time to accommodate if the forms need to be revised and resubmitted. A proposed timeline for the first term is given below.

**Term 1**

- **Week 1.** Get in contact with Jocelyn Coughlin, John Staley (more information in A.4)
- **Week 2.** In-person or video call meetings with Ms. Coughlin, Mr. Staley
- **Week 3.** Submit IRB form and other paperwork for WPS, submit CORI check form
- **Week 4.** Submit IRB form for WPI
- **Week 5-Week 7:** Form processing, correcting/re-submitting forms if needed
During the second term of the project, the team should begin the process of actually performing trial runs of the labs, analyzing the performance of the students, and making revisions to the labs. The current team decided with Ms. Coughlin that it is best to do trial runs over several weeks, focusing on one lab per week. This allows the teachers to best stick to their curriculum, and gives the project team adequate time to explain the project to the students, allow the students to complete the lab, and then discuss and debrief the lab with the students to determine what needs to be improved. A proposed timeline for the second term is given below.

**Term 2**

- Week 1. Trial run #1 of Friction lab
- Week 2. Trial run #1 of Conservation of Energy lab
- Week 3. Trial run #1 of Torque lab
- Week 4. Thanksgiving week, complete revisions of labs
- Week 5. Trial run #2 of Friction lab
- Week 6. Trial run #2 of Conservation of Energy lab
- Week 7. Trial run #2 of Torque lab

**A.3 Important Contacts**

This section outlines a couple of contacts at local Worcester public schools that the current project team was able to get in contact with and who were willing to work with the project.

Jocelyn Coughlin is a physics teacher at Worcester Technical High School. She is willing to allow a project team into her classroom to perform trial runs of the lab modules during her
normally scheduled class time. Ms. Coughlin is willing to be flexible in adjusting her curriculum to fit our schedule if given enough notice.

Jocelyn Coughlin

- Worcester Technical High School
  - 1 Skyline Dr.
  - Worcester, MA 01605
- coughlinj@worcesterschools.net
- 508-799-1980 (WTHS office)

John Staley is the vice principal of Doherty Memorial High School. He does not teach any classes, but oversees the science department and will be the first point of contact for the department. Because of this, it is recommended to reach out to him as early as possible to allow time for him to also communicate with his department and interested teachers.

John Staley

- Doherty Memorial High School
  - 299 Highland St.
  - Worcester, MA 01602
- staleyj@worcesterschools.net

A.4 Required Paperwork and Forms

This section outlines the paperwork and forms that must be completed in order to perform trial runs of the lab modules and collect data in high schools. It is split into three sections: requirements put forth by WPI, those put forth by Worcester Public Schools, and those put forth by the Commonwealth of Massachusetts. Note that the requirements for WPS and Massachusetts
are strictly required, and research with the students is prohibited until all of the requirements are approved.

A.4.1 WPI Requirements

The primary administrative requirement for WPI is completion of the IRB form. This is mandated for all research regarding human subjects, such as students and minors. This form discusses the benefits and risks of the research, as well as protection of data and the identities of subjects. The form also requests write-ups describing the purpose of the study, the protocol, and an informed consent form that all participating subjects must sign. The form begins on the next page and more information, including the most recent version of the application form can be found at:

https://www.wpi.edu/research/resources/compliance/institutional-review-board/
Worcester Polytechnic Institute

Institutional Review Board

WPI IRB Application

WPI Polytechnic Institute IRB# 1
HHS IRB # 00007374

☐ indicates that further documents may be required to explain your study

This application is for: (Please check one) ☐ Expedited Review ☐ Full Review

Principal Investigator (PI) or Project Faculty Advisor: (NOT a student or fellow; must be a WPI employee)

Name: _____________________________ Tel No: ______________________ Address: _____________________________ ☐

Department: __________________________

Co-Investigator(s): (Co-PI(s)/non students)

Name: _____________________________ Tel No: ______________________ E-Mail: _____________________________ ☐

Address: __________________________

Name: _____________________________ Tel No: ______________________ E-Mail: _____________________________ ☐

Address: __________________________

Student Investigator(s):

Name: _____________________________ Tel No: ______________________ E-Mail: _____________________________ ☐

Address: __________________________

Name: _____________________________ Tel No: ______________________ E-Mail: _____________________________ ☐

Address: __________________________

Name: _____________________________ Tel No: ______________________ E-Mail: _____________________________ ☐

Address: __________________________

Name: _____________________________ Tel No: ______________________ E-Mail: _____________________________ ☐

Address: __________________________

Check if: ☐ Undergraduate project (MQP, IQP, Suff., other)
☐ Graduate project (M.S. Ph.D., other)

Has an IRB ever suspended or terminated a study of any investigator listed above? ☐ No ☐ Yes (Attach a summary of the event and resolution.)

Vulnerable Populations: The proposed research will involve the following (Check all that apply):

- pregnant women ☐
- human fetuses ☐
- neonates ☐
- minors/children ☐
- prisoners ☐
- students ☐
- individuals with mental disabilities ☐
- individuals with physical disabilities ☐

Collaborating Institutions: (Please list all collaborating Institutions.)

Locations of Research: (If at WPI, please indicate where on campus. If off campus, please give details of locations.)

Project Title: _____________________________

Funding: (If the research is funded, please enclose one copy of the research proposal or most recent draft with your application.)

Funding Agency: _____________________________ WPI Fund: _____________________________
Human Subjects Research: (All study personnel having direct contact with subjects must take and pass a training course on human subjects research. There are links to web-based training courses that can be accessed under the Training link on the IRB web site http://www.wpi.edu/offices/irb/training.html. The IRB requires a copy of the completion certificate from the course or proof of an equivalent program.)

Anticipated Dates of Research:
Start Date: ___________________________ Completion Date: ___________________________

Instructions: Answer all questions. If you are asked to provide an explanation, please do so with adequate details. If needed, attach itemized replies. Any incomplete application will be returned.

1.) Purpose of Study: (Please provide a concise statement of the background, nature and reasons for the proposed study. Insert below using non-technical language that can be understood by non-scientist members of the IRB.)

2.) Study Protocol: (Please attach sufficient information for effective review by non-scientist members of the IRB. Define all abbreviations and use simple words. Unless justification is provided this part of the application must not exceed 5 pages. Attaching sections of a grant application is not an acceptable substitute.)

A.) For biomedical, engineering and related research, please provide an outline of the actual experiments to be performed. Where applicable, provide a detailed description of the experimental devices or procedures to be used, detailed information on the exact dosages of drugs or chemicals to be used, total quantity of blood samples to be used, and descriptions of special diets.

B.) For applications in the social sciences, management and other non-biomedical disciplines please provide a detailed description of your proposed study. Where applicable, include copies of any questionnaires or standardized tests you plan to incorporate into your study. If your study involves interviews please submit an outline indicating the types of questions you will include.

C.) If the study involves investigational drugs or investigational medical devices, and the PI is obtaining an Investigational New Drug (IND) number or Investigational Device Exemption (IDE) number from the FDA, please provide details.

D.) Please note if any hazardous materials are being used in this study.

E.) Please note if any special diets are being used in this study.
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Institutional Review Board

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IRB File #
Date:

3.) Subject Information:

A.) Please provide the exact number of subjects you plan to enroll in this study and describe your subject population.

(eg. WPI students, WPI staff, UMASS Medical patient, other)

Males: _______ Females: _______ Description: ______________________

B.) Will subjects who do not understand English be enrolled?

No □ Yes □ (Please insert below the language(s) that will be translated on the consent form.)

C.) Are there any circumstances under which your study population may feel coerced into participating in this study?

No □ Yes □ (Please insert below a description of how you will assure your subjects do not feel coerced.)

D.) Are the subjects at risk of harm if their participation in the study becomes known?

No □ Yes □ (Please insert below a description of possible effects on your subjects.)

E.) Are there reasons for excluding possible subjects from this research?

No □ Yes □ (If yes, please explain.)

F.) How will subjects be recruited for participation? (Check all that apply.)

□ Referral: (By whom) __________________________

□ Other: (Identify) __________________________

□ Database: (Describe how database populated)________________________

□ Direct subject advertising, including: (Please provide a copy of the proposed ad. All direct subject advertising must be approved by the WPI IRB prior to use.)

□ Newspaper □ Radio □ Bulletin board

□ Television □ Internet □ Flyers

□ Internet □ Letters □ E-mail

G.) Have the subjects in the database agreed to be contacted for research projects? No □ Yes □ N/A □

H.) Are the subjects being paid for participating? (Consider all types of reimbursement, ex. stipend, parking, travel.)

No □ Yes □ (Check all that apply.) □ Cash □ Check □ Gift certificate □ Other: ______________________

Amount of compensation ______________________

4.) Informed Consent:

A.) Who will discuss the study with and obtain consent of prospective subjects? (Check all that apply.)

□ Principal Investigator □ Co-Investigator(s) □ Student Investigator(s)
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B.) Are you aware that subjects must read and sign an Informed Consent Form prior to conducting any study-related procedures and agree that all subjects will be consented prior to initiating study related procedures?

C.) Are you aware that you must consent subjects using only the IRB-approved Informed Consent Form?

D.) Will subjects be consented in a private room, not in a public space?

E.) Do you agree to spend as much time as needed to thoroughly explain and respond to any subject's questions about the study, and allow them as much time as needed to consider their decision prior to enrolling them as subjects?

F.) Do you agree that the person obtaining consent will explain the risks of the study, the subject’s right to decide not to participate, and the subject's right to withdraw from the study at any time?

G.) Do you agree to either 1.) retain signed copies of all informed consent agreements in a secure location for at least three years or 2.) supply copies of all signed informed consent agreements in .pdf format for retention by the IRB in electronic form?

(If you answer No to any of the questions above, please provide an explanation.)

5.) Potential Risks: (A risk is a potential harm that a reasonable person would consider important in deciding whether to participate in research. Risks can be categorized as physical, psychological, sociological, economic and legal, and include pain, stress, invasion of privacy, embarrassment or exposure of sensitive or confidential data. All potential risks and discomforts must be minimized to the greatest extent possible by using e.g. appropriate monitoring, safety devices and withdrawal of a subject if there is evidence of a specific adverse event.)

A.) What are the risks / discomforts associated with each intervention or procedure in the study?

B.) What procedures will be in place to prevent / minimize potential risks or discomfort?

6.) Potential Benefits:

A.) What potential benefits other than payment may subjects receive from participating in the study?

B.) What potential benefits can society expect from the study?
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7.) Data Collection, Storage, and Confidentiality:

A.) How will data be collected?

B.) Will a subject’s voice, face or identifiable body features (eg. tattoo, scar) be recorded by audio or videotaping?
   No ☐ Yes ☐ (Explain the recording procedures you plan to follow.)

C.) Will personal identifying information be recorded? No ☐ Yes ☐ (If yes, explain how the identifying information will be protected. How will personal identifying information be coded and how will the code be kept confidential?)

D.) Where will the data be stored and how will it be secured?

E.) What will happen to the data when the study is completed?

F.) Can data acquired in the study adversely affect a subject’s relationship with other individuals? (i.e. employee-supervisor, student-teacher, family relationships)

G.) Do you plan to use or disclose identifiable information outside of the investigation personnel?
   No ☐ Yes ☐ (Please explain.)

H.) Do you plan to use or disclose identifiable information outside of WPI including non-WPI investigators?
   No ☐ Yes ☐ (Please explain.)

8.) Incidental findings: In the conduct of information gathering, is it possible that the investigator will encounter any incidental findings? If so, how will these be handled? (An incidental finding is information discovered about a subject which should be of concern to the subject but is not the focus of the research. For example, a researcher monitoring heart rates during exercise could discover that a subject has an irregular heartbeat.)

9.) Deception: (Investigators must not exclude information from a subject that a reasonable person would want to know in deciding whether to participate in a study.)
   Will the information about the research purpose and design be withheld from the subjects?
   No ☐ Yes ☐ (Please explain.)

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10.) Adverse effects: (Serious or unexpected adverse reactions or injuries must be reported to the WPI IRB within 48 hours using the IRB Adverse Event Form found out at http://www.wpi.edu/offices/irb/forms.html. Other adverse events should be reported within 10 working days.)

11.) Conflict of Interest: (A conflict of interest occurs when an investigator or other key personnel in a study may enjoy material benefits based on study results. Relationships that give rise to a conflict of interest or the appearance of a conflict of interest must be disclosed in the informed consent statement provided to study subjects. More information, including examples of relationships that require disclosure and those that do not, can be found here.)

A.) Do any of the investigators listed on this application have a potential or actual conflict of interest with regard to this study?
   a. Investigator (name) ________________ No ☐ Yes ☐
   b. Investigator (name) ________________ No ☐ Yes ☐
   c. Investigator (name) ________________ No ☐ Yes ☐
   d. Investigator (name) ________________ No ☐ Yes ☐

B.) If any of the answers to 11A. are “Yes,” please attach an explanation of the nature of the conflict to this application and identify appropriate language for use in the consent form. Examples of consent language are found on the IRB website, here.

C.) Does each WPI faculty or staff member named as an investigator have a current WPI conflict of interest disclosure form on file with the appropriate supervisor/department head? No ☐ Yes ☐

12.) Informed consent: (Documented informed consent must be obtained from all participants in studies that involve human subjects. You must use the templates available at http://www.wpi.edu/offices/irb/forms.html to prepare these forms. Informed consent forms must be included with this application. Under certain circumstances the WPI IRB may waive the requirement for informed consent.)
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Worcester Polytechnic Institute IRB# 1
HHS IRB # 00007374

Investigator’s Assurance:

I certify the information provided in this application is complete and correct.

I understand that I have ultimate responsibility for the conduct of the study, the ethical performance of the project, the protection of the rights and welfare of human subjects, and strict adherence to any stipulations imposed by the WPI IRB.

I agree to comply with all WPI policies, as well all federal, state and local laws on the protection of human subjects in research, including:

- ensuring the satisfactory completion of human subjects training.
- performing the study in accordance with the WPI IRB approved protocol.
- implementing study changes only after WPI IRB approval.
- obtaining informed consent from subjects using only the WPI IRB approved consent form.
- promptly reporting significant adverse effects to the WPI IRB.

Signature of Principal Investigator

Print full name and title

Date ________________

Please return a signed hard copy of this application to the WPI IRB c/o Ruth McKeogh 2nd Floor Project Center
Or email an electronic copy to irb@wpi.edu

If you have any questions, please call (508) 831-6699.
A.4.2 WPS Requirements

WPS requires all research conducted in classrooms to be approved via the Research Project Application form. It is suggested that this form is requested from either Ms. Coughlin, Mr. Staley, or the WPS Research and Accountability Office so that it can be completed as soon as possible. This application, similar to the WPI IRB, requires a written purpose of study and an informed consent form. For convenience of reference, the form is also copied into this appendix, starting on the next page.
WORCESTER PUBLIC SCHOOLS

RESEARCH PROJECT APPLICATION

Date: __________________________

Name: ____________________________________________________________

Tel #: __________________________________________________________________

E-mail address: ______________________________________________________

College/University Affiliation: __________________________________________

If you are a college/graduate student, name/phone of faculty advisor: ____________

Title of Research Project: ______________________________________________

Purpose of Project: Please attach a one-page description of the proposed research project

Methodology: __________________________________________________________

The number and name of people conducting the research: ____________________________

Estimated completion date: __________________________

Date project is to begin: __________________________

Characteristics of students in the study:

a. Students' age(s): ____________________

b. Students' grade(s): ____________________

c. Number of students in the sample: ____________________

Will the research be conducted during school hours? YES: ________ NO: ________

Estimated time for a student's participation in each session: ________________

Estimated total participation time required of each student: __________________

Will parent(s) be required to participate? YES: ________ NO: ________

Please explain:

a. Number of parents in the sample: ____________________

b. Estimated time for a parent’s participation in each session: ________________

c. Total participation time required of each parent: ____________________

Will teacher(s) be requested to participate? YES: ________ NO: ________

Please explain:

a. Number of teachers in the sample: ____________________

b. Estimated time for a teacher’s participation in each session: ________________

c. Total participation time required of each teacher: ____________________
How will Worcester Public Schools’ students and/or faculty benefit from this project: ____________________________

Have you already discussed this project with school personnel? YES: ___________ NO: ________________

IF YES, whom have you contacted? ____________________________________________________________

Will research participants be compensated? YES: ___________ NO: __________________________

Please Explain ___________________________________________________________________________

_______________________________________________________________________________________

ALL PERSONS CONDUCTING RESEARCH MUST AGREE TO AND SIGN “AGREEMENT REGARDING RESEARCH PROJECTS”

ALL WORCESTER PUBLIC SCHOOLS’ STUDENTS MUST HAVE THE PERMISSION OF THEIR PARENTS/GUARDIANS BEFORE PARTICIPATING IN A RESEARCH PROJECT. PLEASE INCLUDE A SAMPLE OF THE PARENT PERMISSION FORM YOU WILL USE.

FOR SCHOOL DEPARTMENT USE ONLY

SCHOOL: ___________________ PROGRAM: ___________________

APPROVED: ___________________ DATE: ___________________

DISAPPROVED: _________________ DATE: _________________

COMMENT: ___________________

________________________________________________________________________________________

________________________________________________________________________________________

________________________________________________________________________________________

________________________________________________________________________________________

________________________________________________________________________________________

________________________________________________________________________________________

Please e-mail and/or mail completed form to:
Research and Accountability Office
20 Irving Street, Room 202
Worcester, Massachusetts 01609

OR Fax to: 508.799.8277

e-mail: O’NedISP@worc.k12.ma.us
A.4.3 Massachusetts Requirements

In the Commonwealth of Massachusetts, it is required by law for all persons who work with school-age children, including student volunteers, to obtain a criminal record check\(^1\), also known as a CORI check. Worcester Public Schools provides a CORI request form for employees and volunteers for the school district. It can be requested from Ms. Coughlin, Mr. Staley, or from WPS, and must be completed, with photocopies of a valid I.D., and returned to WPS at 20 Irving St. For reference convenience, a copy of the WPS CORI request form is included in this appendix, beginning on the next page.

\(^1\) [http://www.doe.mass.edu/lawsregs/advisory/cori.html](http://www.doe.mass.edu/lawsregs/advisory/cori.html)
In order to volunteer and/or work in the Worcester Public Schools, an individual must have a criminal background check. Convictions will be reviewed to determine an individual’s eligibility to volunteer/work in the Worcester Public Schools. If you have a concern or were not approved, please contact Mark T. Brophy at (508) 799-3027 to determine if you may still be eligible.

This request is submitted by: Department/ School/ Collaborative __________________________

WORCESTER PUBLIC SCHOOLS CORI REQUEST FORM

Worcester Public Schools has been certified by the Criminal History Systems Board for access to all criminal case data including conviction, non-conviction and pending. As an applicant/employee for the position of __________________________, I understand that a criminal record check will be conducted for convictions, non-convictions and pending criminal case information only and that it will not necessarily disqualify me. The information below is correct to the best of my knowledge.

APPLICANT/EMPLOYEE INFORMATION (Please print)

________________________________________
Applicant/Employee Signature

_________________________  __________________________  __________________________
Last Name                  First Name                  Middle Name

_________________________
Maiden Name or Alias (If Applicable)

_________________________
Place of Birth

_________________________
Date of Birth

_________________________
Social Security Number

_________________________
Mother’s Maiden Name

Current and Former Addresses:

_________________________

_________________________

Sex: _______  Height: ___ ft. ___ in.  Weight: _____  Eye Color: ______

State Driver’s License Number: __________________

IN ORDER FOR THIS CORI TO BE PROCESSED, A COPY OF A MASSACHUSETTS ID MUST BE ATTACHED.

_________________________
OFFICE USE ONLY

The above information was verified by reviewing the attached form of government issued photographic identification. ____________________  ____________________
(NAME)  (LOCATION)
WHY A CRIMINAL OFFENDER RECORDS INFORMATION (CORI) CHECK?

In order to protect the welfare of our students, and in accordance with the M.G.L. c.71 §38R, all candidates for, and current occupants of, positions which have the potential for direct and unmonitored contact with WPS students, including, but not limited to teachers, teachers aides, school nurses, counselors, coaches or other extracurricular staff or supervisors, food service employees, custodians and transportation providers. This also includes volunteers, interns, student teachers or other persons regularly offering support to any school program or facility, whether paid or unpaid. This CORI check will be done every three (3) years.

HOW DO I GAIN ENTRY TO A SCHOOL?

In order to be in the schools, individuals (students, faculty, and administrators) from outside institutions must complete a registration process, as follows:

1. Fill out the CORI form on the reverse side of this page so that a CORI check can be done by the Criminal History Systems Board in Boston. Return the form to:

   Human Resource Manager
   Worcester Public Schools
   20 Irving Street
   Worcester, MA 01609

   The Worcester Public Schools will maintain a current data base of all applicants who have been approved or whose approval is pending which can be accessed by each public school. An individual will be contacted only if there appears to be a problem with CORI approval. All information is held in strictest confidence by the Human Resource Manager.

2. On the first visit to the school, verify CORI clearance. You will then complete a brief Registration form which will be kept at the school. Orientation will be provided on-site at the individual school(s). A college ID must be worn at all times when in any Worcester public school.

IS INFORMATION KEPT CONFIDENTIAL?

The CORI process is covered under Massachusetts Law and the statute contains strict language regarding confidentiality: "...any willful, unauthorized dissemination of the CORI may subject the offending agency or individual to a fine of $5,000 and/or up to one year in a House of Correction, in addition to Civil penalties." Within the Worcester Public Schools, CORI information is kept in a confidential file. The Worcester Public Schools is very diligent in not releasing CORI information to anyone other than the specific individual on whom the CORI was conducted.

The Worcester Public Schools is an Equal Opportunity/Affirmative Action Employer/Educational Institution and does not discriminate regardless of race, color, gender, age, religion, national origin, marital status, sexual orientation, disability, or homelessness. The Worcester Public Schools provides equal access to employment and the full range of general, occupational and vocational education programs. For more information relating to Equal Opportunity/Affirmative Action contact Stacey DeBoise Luster, Human Resource Manager, 20 Irving Street, Worcester, MA 01609. 508-799-3020. Please call the main office at the school if you would like this document translated into a language other than English.

Por favor, contate a secretaria central da escola si usted desea que este documento seja traduzido para o português.

Ju lutem telefononi zyren qendrore te shkolles ne se deshironi ta kini kete dokument te perkthyer ne nje gjyhe tjeter pervec Anglishtes

Xin gửi điện thoại cho văn phòng nhà trường nếu quý vị muốn tài liệu này được dịch ra một ngôn ngữ khác hơn tiếng Anh

83
Appendix B - Survey for WPI SPS

This survey, which is shown on the next page, was used during the event with WPI’s chapter of the Society of Physics Students. The members of the organization first got accustomed to the lab set up and accompanying worksheet for each lab module. They then completed the survey, first ranking several statements on the Likert scale, and then giving any other suggestions to further improve the lab or worksheet. During the activity, the members were also encouraged to leave comments and suggestions on a copy of the worksheet so that the project team could make specific changes.
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year:

Which of these classes have you taken? (Circle) PH 1110/1111  PH 2201  PH 2202  PH 2651/2510/2601

Have you PLA’d a mechanics class? If so, which one(s)?

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
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What learning style do you think fits your needs the best? Explain.

- visual
- auditory
- kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?

85
Appendix C - Friction Lab

C.1 SPS Event Results

This section will contain the results, beginning on the next page, from the event with WPI’s chapter of the Society of Physics Students (SPS). The first page will include a blank version of the original worksheet used during the event (prior to alterations). The next page will be a scanned copy of the worksheet with corrections and suggestions from the members of SPS. The following eight pages will then be scanned copies of the surveys from each of the members that evaluated the friction lab module.
This lab will focus on the concept of friction. Through the lab, you will focus on the differences between static friction and kinetic friction and how friction affects motion. At the end, you will have calculated the coefficient of kinetic friction between your cardboard ramp and the wooden block.

1. Set up the ramp so that it has an angle great enough that the block slides down the ramp.

2. If the block does not slide down the ramp, how does the force of friction compare to the force due to gravity? What type of friction is acting on the block?

3. Use an angle finding app such as Angle Meter (Android) or the level in the Measurement app (iPhone) in order to determine the angle of elevation, $\theta$, of the ramp.

   $\theta = \ldots \degree$

4. Use the equation $a_p = g \sin \theta \sin \theta$ to determine acceleration of block due to gravity.

   $a_p = \ldots \text{ m/s}$

5. Place the block on the ramp. Measure the distance $d$ from the bottom of the ramp to the block, as shown in the force diagram.

   $d = \ldots \text{ m}$

6. Using the stopwatch, find time $t$ for how long it takes for the block to slide all the way down the ramp, starting from rest.

7. Use the equation $a_a = \frac{2d}{t^2}$ to calculate the actual acceleration of the block down the ramp.

   $a_a = \ldots \text{ m/s}$

8. How does predicted acceleration compare to actual acceleration? What does this tell us about how friction affects motion?

9. Use the equation $\mu_k = \frac{a_a - a_p}{g \cos \theta}$ to determine the coefficient of kinetic friction between the cardboard and wooden block.

   $\mu_k = \ldots$

10. How does increasing the angle of elevation of the ramp affect normal force, the theoretical acceleration of the block, and the coefficient of kinetic friction?
The lab will focus on the concept of friction. Through the lab, you will focus on the differences between static friction and kinetic friction and how friction affects motion. At the end, you will have calculated the coefficient of kinetic friction between your cardboard ramp and the block.

1. Set up the ramp so that it has an angle great enough that the block slides down the ramp.
2. If the block does not slide down the ramp, how does the force of friction compare to the force due to gravity? What type of friction is acting on the block?

3. Use an angle finding app such as Angle Meter (Android) or the level in the Measurement app (iPhone) in order to determine the angle of elevation, θ, of the ramp.

4. Use the equation \( a_p = g \sin \theta \) to determine acceleration of block due to gravity.

5. Place the block on the ramp. Measure the distance \( d \) from the bottom of the ramp to the block, as shown in the force diagram.

6. Using the stopwatch, find time \( t \) for how long it takes for the block to slide all the way down the ramp, starting from rest.

7. Use the equation \( a_d = \frac{2d}{t^2} \) to calculate the actual acceleration of the block down the ramp.

8. How does predicted acceleration compare to actual acceleration? What does this tell us about how friction affects motion?

9. Use the equation \( \mu_k = \frac{a - a_d}{g \cos \theta} \) to determine the coefficient of kinetic friction between the cardboard and wooden block. Where \( \mu_k \) is the coeff... or something

10. How does increasing the angle of elevation of the ramp affect normal force, the theoretical acceleration of the block, and the coefficient of kinetic friction?
Lab Surveying: (Friction) Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year:

Which of these classes have you taken? (Circle) PH 1110/1111 PH 2201 PH 2202 PH 2651/2510/2601

Have you PLA’d a mechanics class? If so, which one(s)?

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What learning style do you think fits your needs the best? Explain.

- visual
- auditory
- kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?

the laboratories could also involve measuring static friction as well though that might make the lab too long

89
Lab Surveying: *Friction / Energy / Torque*

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: 2022

Which of these classes have you taken? (Circle) PH 1110/1111 PH 2201 PH 2202 PH 2651/2510/2601

Have you PLA’d a mechanics class? If so, which one(s)? None

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What learning style do you think fits your needs the best? Explain.
visual

auditory

kinesthetic (hands-on)

Doing things helps me learn better than listening

Do you have any further comments/suggestions? Anything that you would change?

I always find FBDs helped me understand friction better so maybe ask explicitly to draw an FBD of the box
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: 2022

Which of these classes have you taken? (Circle) PH 1110/1111 PH 2201 PH 2202 PH 2651/2510/2601

Have you PLA'd a mechanics class? If so, which one(s)?

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What learning style do you think fits your needs the best? Explain.
- visual
- auditory
- kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?

This is very well written, might want to clear some writing up. You guys are doing great! ❤️
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: 2019 Senior

Which of these classes have you taken? (Circle) PH 1110/1111  PH 2201  PH 2202  PH 2651/2510/2601

Have you PLA’d a mechanics class? If so, which one(s)?

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What learning style do you think fits your needs the best? Explain.

visual

auditory

kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?

maybe change the material on the ramp and see how it effects things? like carpet, paper, grass, IDK.
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: Senior

Which of these classes have you taken? (Circle) PH 1110 PH 1111 PH 2200 PH 2202 PH 2631/2510/2601

Have you PLA’d a mechanics class? If so, which one(s)? Yes, PH 1110

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What learning style do you think fits your needs the best? Explain.

- visual
- auditory
- kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?

Maybe just add one sub part that asks them explicitly to guess the equation of force due to friction.
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: Senior

Which of these classes have you taken? (Circle) PH 1110/1111, PH 2201, PH 2202, PH 2651/2510/2601

Have you PLA’d a mechanics class? If so, which one(s)? PH 1111, PH 1110

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What learning style do you think fits your needs the best? Explain.
- visual
- auditory
- kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?

More explanation of eavns. maybe
Lab Surveying / Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: 2022

Which of these classes have you taken? (Circle) PH 11101111 PH 2201 PH 2202 PH 2651/2510/2601

Have you PLA’d a mechanics class? If so, which one(s)?

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What learning style do you think fits your needs the best? Explain.

visual

auditory

kinesthetic (hands-on)

Kinesthetic since it prepares you for your future job and you can learn to fix your mistakes.

Do you have any further comments/suggestions? Anything that you would change?

- Give more detailed instructions
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: Senior

Which of these classes have you taken? (Circle) PH 1110/1111 PH 2201 PH 2202 PH 2651/2510/2601

Have you PLA’d a mechanics class? If so, which one(s)?

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What learning style do you think fits your needs the best? Explain.

  visual

  auditory

kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?
C.2 Teacher’s Manual

The teacher’s manual, which begins on the next page, is to aid the instructor of an introductory mechanics course in implementing the friction lab module in their classroom. It includes a list of the learning objectives for the lab module, the materials for the lab set up, and the protocol and questions from the worksheet. The manual provides additional information, such as how to use the lab materials to produce the set up, that the worksheet does not cover to further eliminate ambiguity in the learning objectives, protocol, and questions in the lab. The addition of this teacher’s manual to the lab kit allows the lab modules to be more easily implemented in a classroom without extensive training for the instructor.
Friction Lab Teacher’s Manual

This teacher’s manual is designed to aid an instructor in implementing the friction lab module in their classroom. This includes the learning objectives that the lab is designed to focus on, the materials needed to produce the lab set up, and the protocol and questions used in the worksheet.

Learning Objectives

This is a basic set of learning objectives for the concept of friction. These learning objectives are the basis for the questions and calculations in the worksheet. The learning objectives can be further expanded on by the instructor’s personal additions to the questions and calculations performed in the worksheet, if time permits.

- Calculate the predicted acceleration of block down a slope with a given angle.
- Describe the differences between static and kinetic friction.
- Describe the direction in which friction acts and how it affects motion.
- Calculate the coefficient of kinetic friction using force of friction and normal force.

Materials

This is a recommended set of materials to be used for the lab set up. Changes can be made at the instructor’s discretion as necessary or desired.

- Cardboard sheet
  - At least 36 inches long
  - At least 6 inches wide
- Block
  - Approximately 4 inches long and 4 inches wide or smaller
  - Various materials can be used, but wood is recommended
- Ruler
- Smartphone
  - Includes a stopwatch application
  - Includes an angle measuring application such as Angle Meter (Android) or the level in the Measurement app (iPhone)
- Scissors or, preferably, box cutter
  - Used to cut cardboard sheet into ramp, not used in lab set up
- Tape
Used to tape the ramp down on a table

Designing the Set up

This is the recommended method of using the lab materials listed above to produce a lab set up. This process will need to be altered by the instructor if different materials are used.

Ramp

The final product, when assembled, will look like the diagram in Figure 1 below the instructions.

1. Cut the cardboard sheet so that it is approximately 6 inches wide and at least 36 inches long.

2. Lay cardboard sheet flat so that it goes left to right lengthwise.

3. Measure ~2 inches from the left end and lightly cut straight down from the top of the sheet to the bottom. The cut should be so to slice through the first layer of the cardboard but not completely through; then, the cardboard can be bent under. This 2 inch section will be a small lip to lie flat on the table to be taped down.

4. Repeat Step 3, this time measuring ~2 inches from the right end of the sheet. This will form a second lip to tape the ramp down with.

5. Locate the center of the sheet between the two vertical cuts. Measure ~2 inches to the right of the center, and make another light cut straight down from the top of the sheet to the bottom. The longer section will act as the main body of the ramp, which the block will slide down. The shorter section will act as one leg of the ramp, which can be moved in and out to adjust the angle of elevation.

Figure 1: A diagram of how the cardboard sheet will form the ramp used in the friction module.
Protocol

This is the protocol that the students will go through while performing the lab activity. Calculations and conceptual questions are mixed with performing measurements to increase conceptual learning. Additional conceptual questions or calculations can be added by the instructor if desired.

1. Set up the ramp so that it has an angle just great enough that block slides down it.

2. **Conceptual Question 1**

3. Use an angle measuring app such as Angle Meter (Android) or the level in the Measurement app (iPhone) in order to determine the angle of elevation, $\theta$, of the ramp.

4. Use the equation $a_p = g \sin \theta$ to determine the predicted acceleration of the block down the ramp without friction.

5. Place the block on the ramp. Measure the distance $d$ from the bottom of the ramp to the bottom of the block, as shown in the diagram.

6. Use a stopwatch to find the time $t$ that it takes for the block to slide all the way down the ramp, starting from rest.

7. Use the equation $a_a = \frac{2d}{t^2}$ to calculate the actual acceleration of the block down the ramp.

8. **Conceptual Question 2**

9. Use the equation $\frac{a_p - a_a}{g \cos \theta}$ to determine the coefficient of kinetic friction, $\mu_k$, between the cardboard and the block.

Conceptual Questions

These are the conceptual questions included in the worksheet accompanying the friction lab module, followed by the expected response for the question. The numbers below match with the numbers used in the Protocol above. Additional conceptual questions can be added by the instructor if desired.

1. If the block does not slide down the ramp, how does the force of friction compare to the force due to gravity? What type of friction is acting on the block?

   *Expected Response: Force of friction is greater than the force due to gravity. Static friction is acting on the block.*

2. How does predicted acceleration, $a_p$, compare to actual acceleration, $a_a$? What does this tell us about how friction affects motion?

   *Expected Response: Predicted acceleration, $a_p$, is greater than actual acceleration, $a_a$. This tells us that friction opposes motion.*
C.3 Accompanying Worksheet

The worksheet, which begins on the next page, accompanies the lab friction module set up. This worksheet has been revised from the worksheet in C.1 according to suggestions and survey results from the Society of Physics Students at WPI. The worksheet contains a protocol for collecting several measurements, conceptual questions, and calculations which eventually lead to the calculation of the coefficient of kinetic friction between the ramp and the block. The conceptual questions and calculations are mixed in with the collection of measurements in order to increase conceptual learning, as was found in the literature review portion of the project. Furthermore, the worksheet is only on one page to minimize printing costs and time to complete.
Friction Lab

This lab will focus on the concept of friction. Throughout the lab, you will focus on the differences between static friction and kinetic friction and how friction affects motion. At the end, you will have calculated the coefficient of kinetic friction between your cardboard ramp and the block.

1. Set up the ramp so that it has an angle just great enough that block slides down it.
2. If the block does not slide down the ramp, how does the force of friction compare to the force due to gravity? What type of friction is acting on the block?

3. Use an angle measuring app such as Angle Meter (Android) or the level in the Measurement app (iPhone) in order to determine the angle of elevation, θ, of the ramp.

\[ \theta = \ \text{__________} ^\circ \]

4. Use the equation \( a_p = g \sin \theta \) to determine the predicted acceleration of the block down the ramp without friction.

\[ a_p = \ \text{__________} \ m/s^2 \]

5. Place the block on the ramp. Measure the distance \( d \) from the bottom of the ramp to the bottom of the block, as shown in the diagram.

\[ d = \ \text{__________} \ m \]

6. Use a stopwatch to find the time \( t \) that it takes for the block to slide all the way down the ramp, starting from rest.

\[ t = \ \text{__________} \ s \]

7. Use the equation \( a_a = \frac{2d}{t^2} \) to calculate the actual acceleration of the block down the ramp.

\[ a_a = \ \text{__________} \ m/s^2 \]

8. How does predicted acceleration, \( a_p \), compare to actual acceleration, \( a_a \)? What does this tell us about how friction affects motion?

9. Use the equation \( \frac{a_p - a_a}{g \cos \theta} \) to determine the coefficient of kinetic friction, \( \mu_k \), between the cardboard and the block.

\[ \mu_k = \ \text{__________} \]
Appendix D - Conservation of Energy Lab

D.1 SPS Event Results

This section will contain the results, beginning on the next page, from the event with WPI’s chapter of the Society of Physics Students (SPS). The first page will include a blank version of the original worksheet used during the event (prior to alterations). The next page will be a scanned copy of the worksheet with corrections and suggestions from the members of SPS. The following six pages will then be scanned copies of the surveys from each of the members that evaluated the conservation of energy lab module.
Conservation of Energy - Lab

Learning Objectives:
- understand that energy is conserved in an ideal system
- understand that energy is transferred through different forms as an object moves
- identify the types of mechanical energy present in an oscillating system

Materials:
- spring
- paperclips (2)
- washers (6-9)
- small dowel
- clamp
- meter stick

Procedure:
1. Clamp the dowel to the edge of a table or desk.
2. Attach one paper clip to each end of the spring.
3. Hang the spring on the dowel by one paperclip, and attach the washers to the paperclip on the other end.
4. Stand the meter stick so it’s vertical next to the system.
5. Take a slow motion video of the apparatus as it’s set into motion. Be sure to capture at least one full cycle. Use a cellphone as a timer in the frame to track how long the cycle takes.

Questions:
1. Fill in the table below to identify which types of mechanical energy are present at each point in the oscillation.

<table>
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<th></th>
<th>mass @ +10cm</th>
<th>mass @ 0cm</th>
<th>mass @ -10cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>elastic potential energy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gravitational potential energy</td>
<td></td>
<td></td>
<td></td>
</tr>
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2. Calculate the velocity of the mass at the center of its cycle (where the spring is unstretched) using the time and distance from your video.
Conservation of Energy - Lab

Learning Objectives:
- Understand that energy is conserved in an ideal system
- Understand that energy is transferred through different forms as an object moves
- Identify the types of mechanical energy present in an oscillating system

Materials:
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2. Calculate the velocity of the mass at the center of its cycle (where the spring is unstretched) using the time and distance from your video.

Wouldn't using time & distance from video only calculate average velocity? This is very unclear. Which time? Full period or full distance & \( v = \frac{d}{t} \) will give avg. vel. not instantaneous vel. at center of cycle.

Needs more questions to make them think & explain how energy works. Don't delve as deep as other labs.
Lab Surveying: Friction (Energy) Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: 2022

Which of these classes have you taken? (Circle) PH 1110/1111 PH 2201 PH 2202 PH 2651/2510/2601

Have you PLA’d a mechanics class? If so, which one(s)?

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What learning style do you think fits your needs the best? Explain.

visual

auditory

kinesthetic (hands-on)

hands-on activities are better for remembering concepts and seeing how things interact

Do you have any further comments/suggestions? Anything that you would change?

Detailed instructions
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: Senior

Which of these classes have you taken? (Circle) PH 1110/1111, PH 2201, PH 2202, PH 2651, PH 2510/2601

Have you PLA’d a mechanics class? If so, which one(s)? PH 1110, PH 1111

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What learning style do you think fits your needs the best? Explain.

- Visual
- Auditory
- Kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?
Lab Surveying: Friction ≠ Energy = Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: 2022

Which of these classes have you taken? (Circle) PH 1110/1111 PH 2201 PH 2202 PH 2651/2510/2601

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Do you have any further comments/suggestions? Anything that you would change?

maybe add the equations to sheet for clarity! you guys are doing great! ✨
Lab Surveying: Friction (Energy) Torque

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Year: 2022

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<td>I feel that the lab was clear, concise, and easy to follow.</td>
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</tbody>
</table>

What learning style do you think fits your needs the best? Explain.

Visual
Auditory
Kinesthetic (hands-on)

I remember things I do better than things I hear

Do you have any further comments/suggestions? Anything that you would change?

I like the lab, it's simple and effective. The only thing I would change is being more explicit about the distance its pulled and taking the video

109
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: Senior

Which of these classes have you taken? (Circle) PH 1110/2201/2202/2651/2510/2601

Have you PLA’d a mechanics class? If so, which one(s)? Yes, 1110

<table>
<thead>
<tr>
<th>The lab demonstrated physical concepts well.</th>
<th>Strongly Agree</th>
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What learning style do you think fits your needs the best? Explain.

visual, auditory, kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?

Add a part to the table for total energy; they may need to know equations for other rows. At the end ask a question specifically about how the initial energy compares to the final energy. Add a way for the students to indicate which point of measurement was taken first second, last. It may be confusing that the table says 0 cm because...
Lab Surveying: Friction Energy Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year:

Which of these classes have you taken? (Circle) PH 1110/1111 PH 2201 PH 2202 PH 2651/2510/2601

Have you PLA’d a mechanics class? If so, which one(s)?

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What learning style do you think fits your needs the best? Explain.

visual
auditory
kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?

be more descriptive with the setup
use diagrams
relate observations to equations
delve deeper like the other labs, ask more for the students to think about
D.2 Teacher’s Manual

The teacher’s manual, which begins on the next page, is to aid the instructor of an introductory mechanics course in implementing the conservation of energy lab module in their classroom. It includes a list of the learning objectives for the lab module, the materials for the lab set-up, and the protocol and questions from the worksheet. The manual provides additional information, such as how to use the lab materials to produce the set-up, that the worksheet does not cover to further eliminate ambiguity in the learning objectives, protocol, and questions in the lab. The addition of this teacher’s manual to the lab kit allows the lab modules to be more easily implemented in a classroom without extensive training for the instructor.
Conservation of Energy Lab Teacher’s Manual

This teacher’s manual is designed to aid an instructor in implementing the conservation of energy lab module in their classroom. This includes the learning objectives that the lab is designed to focus on, the materials needed to produce the lab set up, and the protocol and questions used in the worksheet.

Learning Objectives

This is a basic set of learning objectives for the concept of conservation of energy. These learning objectives are the basis for the questions and calculations in the worksheet. The learning objectives can be further expanded on by the instructor’s personal additions to the questions and calculations performed in the worksheet, if time permits.

- Describe how energy is conserved in an ideal system.
- Describe how energy is transferred to different forms as an object moves.
- Identify the types of mechanical energy present in an oscillating system.

Materials

This is a recommended set of materials to be used for the lab set up. Changes can be made at the instructor’s discretion as necessary or desired.

- Small wooden dowel
- C-clamp (to hold to dowel in place)
- 2 paper clips per set
- 15 washers per set (small, approximately the size of a dime)
- Small springs (approximately 30 N/m)
- Meter stick
- Smartphone with a stopwatch or manual stopwatch
- Smartphone with slow-motion video capabilities

Protocol

This is the protocol that the students will go through while performing the lab activity. Additional conceptual questions or calculations can be added by the instructor if desired.

1. Clamp the dowel to the edge of a table or desk such that approximately one-third of the length is off the edge.

   The dowel should be as stationary as possible during the experiment, so it is okay to have the clamp slightly tighter than expected.

2. Attach one paper clip to each end of the spring.
These can be either left in their original condition for stability or bent into a different shape for flexibility.

3. Hang the spring on the dowel by one paperclip, and attach the washers to the paperclip on the other end.
4. Stand the meter stick so it’s vertical next to the system (as if to measure the height of the washers).
5. Arrange a stopwatch (either physical or on a smartphone) so it’s next to the system.
6. Set up a smartphone camera to record the system and its motion. Be sure to have the stopwatch in frame.
7. Start the stopwatch, and then start recording a slow-motion video. The system should look similar to Figure A.
8. While the stopwatch and video are running, pull the washers down 10 cm from their rest point (so they resemble Figure B).
9. Let go of the washers.
10. Stop the video after the washers have returned to the lowest point (shown in Figure B below).

Conceptual Questions

These are the conceptual questions included in the worksheet accompanying the conservation of energy lab module, followed by the expected response for the question. Additional conceptual questions can be added by the instructor if desired.

1. Using the following list, indicate on each of the figures below which types of energy are present.
   \[ GPE = mgh \quad EPE = \frac{1}{2}kx^2 \quad KE = \frac{1}{2}mv^2 \]
   Expected responses should write GPE and EPE in Figures B and D, KE in Figure C.

2. Using the video:
   This question is less conceptual and based in data collection and utilization. This process describes obtaining an average velocity of the washers at the center point of the oscillation. These results may vary depending on the set-up, exact materials, etc.

3. Calculate the total energy of the system in each figure below.
   Expected responses may vary.
   How does the energy compare from one figure to another?
   The energies should be somewhat similar, but will most likely by different due to friction, approximation of an instantaneous velocity as an average velocity, etc.
   Would the energies differ in an ideal system (without air resistance, friction, and other sources of error?)
   Expected responses may vary, but should mention that in the absence of nonconservative forces, energy is conserved.
D.3 Accompanying Worksheet

The worksheet, which begins on the next page, accompanies the conservation of energy lab module set-up. This worksheet has been revised from the worksheet in D.1 according to suggestions and survey results from the Society of Physics Students at WPI. The worksheet contains a protocol for collecting several measurements, conceptual questions, and calculations which eventually lead to the calculation of the total energy of the washer-spring system at different points. The conceptual questions and calculations are mixed in with the visual representation of the lab in order to increase conceptual learning, as was found in the literature review portion of the project. Furthermore, the worksheet is only on one page to minimize printing costs and time to complete.
**Lab - Conservation of Energy**

<table>
<thead>
<tr>
<th>Materials:</th>
<th>Procedure:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Spring</td>
<td>1. Clamp the dowel to the edge of a table or desk such that approximately one-third of the length is off the edge.</td>
</tr>
<tr>
<td>- Paperclips</td>
<td>2. Attach one paper clip to each end of the spring.</td>
</tr>
<tr>
<td>(2)</td>
<td>3. Hang the spring on the dowel by one paperclip, and attach the washers to the paperclip on the other end.</td>
</tr>
<tr>
<td>- Washers (15)</td>
<td>4. Stand the meter stick so it’s vertical next to the system (as if to measure the height of the washers).</td>
</tr>
<tr>
<td>- Small dowel</td>
<td>5. Arrange a stopwatch (either physical or on a smartphone) so it’s next to the system.</td>
</tr>
<tr>
<td>- Clamp</td>
<td>6. Set up a smartphone camera to record the system and its motion. Be sure to have the stopwatch in frame.</td>
</tr>
<tr>
<td>- Meter stick</td>
<td>7. Start the stopwatch, and then start recording a slow-motion video. The system should look similar to Figure A.</td>
</tr>
<tr>
<td></td>
<td>8. While the stopwatch and video are running, pull the washers down 10 cm from their rest point (so they resemble Figure B).</td>
</tr>
<tr>
<td></td>
<td>9. Let go of the washers.</td>
</tr>
<tr>
<td></td>
<td>10. Stop the video after the washers have <em>returned</em> to the lowest point (shown in Figure B below).</td>
</tr>
</tbody>
</table>

**Questions:**

1. Using the following list, indicate on each of the figures below which types of energy are present.

\[
P_E = mgh \quad E_P = \frac{1}{2}kx^2 \quad K_E = \frac{1}{2}mv^2
\]

2. Using the video:

   - Note the time when the washers were at \( h = 1 \) cm (1 cm higher than the original rest point):
   - Note the time when the washers were at \( h = -1 \) cm (1 cm lower than the original rest point):
   - Add those two times together:
   - Divide the distance traveled in that interval (2 cm total) by that total time:

3. Calculate the total energy of the system in each figure below.

How does the energy compare from one figure to another?

Would the energies differ in an ideal system (without air resistance, friction, other sources of error)?

---

![Figure A](image1.png)

![Figure B](image2.png)

![Figure C](image3.png)

![Figure D](image4.png)

*this image is not to scale!
Appendix E - Torque Lab

E.1 SPS Event Results

This section will contain the results, beginning on the next page, from the event with WPI’s chapter of the Society of Physics Students (SPS). The first page will include a blank version of the original worksheet used during the event (prior to alterations). The next four pages will be a scanned copy of the worksheet with corrections and suggestions from the members of SPS. The following six pages will then be scanned copies of the surveys from each of the members that evaluated the torque lab module.
Torque Lab

Background:

As you have learned, forces acting on objects cause them to accelerate in a certain direction, but what is involved to give an object rotational acceleration (spinning or rotating) about an axis? This can be attributed to torque, the formula for which is $\tau = Fl\sin\theta$, where $F$ is the force, $l$ is the length between the pivot point and the force, and $\theta$ is the angle between force and length. The purpose of this lab activity is to experimentally show that this equation above is true.

Materials:

- 12” ruler
- Protractor (or phone level?)
- Spring scale
- Masking tape
- 10 stacked washers taped together
- a pencil

Procedure:

1. Tape the stack of washers to the 0” end of the ruler, then tape the pencil to the bottom side of the ruler at the 6” line. Next, tape the pencil to the edge of the table so it is parallel with the edge (the ruler should be perpendicular and hanging off the edge).
2. For the first set of measurements, keep the spring scale vertically perpendicular to the ruler, and measure the force required to keep the ruler leveled at 5 different distances (and make sure your distances are recorded in meters!).
3. For the second set of measurements, tape the spring scale to the ruler at the 9” line. Then measure the force required to keep the ruler level at 5 different angles (two < 90, one at 90, and two > 90)

<table>
<thead>
<tr>
<th>Distance</th>
<th>Force</th>
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<tbody>
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</tbody>
</table>
Questions:

1. Is torque constant in this experiment?

2. Solve $\tau = F \sin \theta$ for force.

3. Graph force vs. distance and force vs. angle.

4. Do the shapes of the graphs match this equation when $\theta = 90^\circ$, with a changing $l$? When $l = .07m$ with a changing $\theta$? (Hint: if a variable is constant, set it equal to 1)
Torque Lab

Background:
As you have learned, forces acting on objects cause them to accelerate in a certain direction, but what is involved to give an object rotational acceleration (spinning or rotating) about an axis? This can be attributed to **torque**, the formula for which is, where \( \tau \) is the force, \( l \) is the length between the pivot point and the force, and \( \theta \) is the angle between force and length. The purpose of this lab activity is experimentally show that this equation above is true.

Materials:
- A positive attitude
- 12” ruler
- Protractor (or phone level?)
- Spring scale
- Masking tape
- 10 stacked washers taped together
- A pencil

Procedure:
1. Tape the stack of washers to the 0” end of the ruler, then tape the pencil to the bottom side of the ruler at the 6” line. Next, tape the pencil to the edge of the table so it is parallel with the edge (the ruler should be perpendicular and hanging off the edge).
2. For the first set of measurements, keep the spring scale vertically perpendicular to the ruler (\( \tau \)), and measure the force required to keep the ruler leveled at 5 different distances (and make sure your distances are recorded in meters!).
3. For the second set of measurements, tape the spring scale to the ruler at the 9” line. Then measure the force required to keep the ruler level at 5 different angles (two < 90, one at 90, and two > 90).

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<td>&lt;90</td>
<td></td>
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<tr>
<td>90</td>
<td></td>
</tr>
</tbody>
</table>
Questions:

1. Is torque constant in this experiment? (This means it doesn't change)

2. Solve for force.

(On the back?)

3. Graph force vs. distance and force vs. angle.

4. Do the shapes of the graphs match this equation when \( l \) with a changing \( l \)? When \( l = \) .07m with a changing \( \theta \)? (Hint: if a variable is constant, set it equal to 1).
Torque Lab

Background:
As you have learned, forces acting on objects cause them to accelerate in a certain direction, but what is involved to give an object rotational acceleration (spinning or rotating) about an axis? This can be attributed to the concept of torque, the formula for which is

\[ \tau = \theta \cdot \ell \]

where \( \tau \) is the torque, \( \theta \) is the angle between the pivot point and the force, and \( \ell \) is the length between force and length. The purpose of this lab activity is to experimentally show that this equation above is true.

Materials:
- 12" ruler
- Protractor (or phone level?)
- Spring scale
- Masking tape
- 10 stacked washers taped together
- a pencil

Procedure:
1. Tape the stack of washers to the 0" end of the ruler, then tape the pencil to the bottom side of the ruler at the 6" line. Next, tape the pencil to the edge of the table so it is parallel with the edge (the ruler should be perpendicular and hanging off the edge).
2. For the first set of measurements, keep the spring scale vertically perpendicular to the ruler \( \theta \), and measure the force required to keep the ruler leveled at 5 different distances (and make sure your distances are recorded in meters!).
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Questions:

1. Is torque constant in this experiment?

2. Solve for force.
   (On the back?)

3. Graph force vs. distance and force vs. angle.

4. Do the shapes of the graphs match this equation when \( l \), with a changing \( l \)? When \( l = 0.07 \text{m} \) with a changing \( \theta \)? (Hint: if a variable is constant, set it equal to 1)

   [Diagram]

   This is confusing.
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: Senior ✔

Which of these classes have you taken? (Circle) PH 1110/1111 PH 2201 PH 2202 PH 2651/2652 2510/2601

Have you PLA’ed a mechanics class? If so, which one(s)?

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What learning style do you think fits your needs the best? Explain.

visual
auditory
kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: 2022

Which of these classes have you taken? (Circle) PH 1110 1111 PH 2201 PH 2202 PH 2651/2510/2601

Have you PLA’d a mechanics class? If so, which one(s)?

<table>
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What learning style do you think fits your needs the best? Explain.

visual  auditory  kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?

A diagram might be helpful.
Increase weight needed (for the erasers).
Specify which direction to pull.
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: 

Which of these classes have you taken? (Circle) PH 1110/1111 PH 2201 PH 2202 PH 2651 PH 2610 PH 2601

Have you PLA'd a mechanics class? If so, which one(s)?

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<th>Statement</th>
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What learning style do you think fits your needs the best? Explain. visual auditory kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?

errors/issues with lab instruction, did not specify erases should be on table, or motion indicated use of paper cup. I suspect the lab would work better with 4 erases instead of 3. Instructions might as well subtly introduce vectors, etc.
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: **Senior**

Which of these classes have you taken? (Circle) PH 1110/1111 / PH 2201 / PH 2202 / PH 2651 / 2510 / 2601

Have you PLA’d a mechanics class? If so, which one(s)? PH 1110, PH 1111

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What learning style do you think fits your needs the best? Explain.

1. **Visual**
2. **Auditory**
3. **Kinesthetic (Hands-on)**

Do you have any further comments/suggestions? Anything that you would change?
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: Senior

Which of these classes have you taken? (Circle) PH 1110/1112 PH 2201 PH 2202 PH 2651 2510/2601

Have you PLA’d a mechanics class? If so, which one(s)? Yes 1110

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What learning style do you think fits your needs the best? Explain.

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auditory

kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?

I like the graphing portion on the back, great idea, consider using a smartphone for the mass or something other than the erasers. Asking them to guess the equation at the end would be a nice touch.
Lab Surveying: Friction / Energy / Torque

PLEASE BE AS HONEST AS POSSIBLE. CONSTRUCTIVE CRITICISM IS WELCOME.

Year: 2022

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What learning style do you think fits your needs the best? Explain.

- visual
- auditory
- kinesthetic (hands-on)

Do you have any further comments/suggestions? Anything that you would change?

"Make sure to be more specific in the instructions. Maybe include more conversation with the students and
more group discussion. Maybe more led for things to guess. I think the students should be given more
ideas and questions and why the angle and distance effects the force."
E.2 Teacher’s Manual

The teacher’s manual, which begins on the next page, is to aid the instructor of an introductory mechanics course in implementing the torque lab module in their classroom. It includes a list of the learning objectives for the lab module, the materials for the lab set up, and the protocol and questions from the worksheet. The manual provides additional information, such as how to use the lab materials to produce the set up, that the worksheet does not cover to further eliminate ambiguity in the learning objectives, protocol, and questions in the lab. The addition of this teacher’s manual to the lab kit allows the lab modules to be more easily implemented in a classroom without extensive training for the instructor.
Torque Lab Teacher’s Manual

This teacher’s manual is designed to aid an instructor in implementing the torque lab module in their classroom. This includes the learning objectives that the lab is designed to focus on, the materials needed to produce the lab set up, and the protocol and questions used in the worksheet.

Learning Objectives

This is a basic set of learning objectives for the concept of torque. These learning objectives are the basis for the questions in the worksheet. The learning objectives can be further expanded on by the instructor’s personal additions to the questions and calculations performed in the worksheet.

- Describe why torque is kept constant throughout the activity.
- Graph force vs. distance and force vs. angle.
- Solve for force \( F \) using the formula for torque \( \tau = F \sin \theta \).
- Show that \( F \) is proportional to \( 1/l \) with constant angle.
- Show that \( F \) is proportional to \( 1/\sin \theta \) with constant distance

Materials

This is a recommended set of materials to be used for the lab set up. Changes can be made at the instructor’s discretion as necessary or desired.

- A pencil
  - To act as a fulcrum
- Ruler
- Erasers or washers
  - A stack of 5 large erasers or 20 1” flat washers; taped together
  - To act as a weight, can use other materials
- Smartphone
  - Includes an angle measuring application such as Angle Meter (Android) or the level in the Measurement app (iPhone)
- Dynamometer (spring scale)
  - Make sure that it can measure enough difference in force for the corresponding weight
- Masking tape
  - Used to tape erasers/washers together, then to the ruler
  - To tape pencil to table
Designing the Set up

This is the recommended method of using the lab materials listed above to produce a lab set up. This process will need to be altered by the instructor if different materials are used.

Setup

The final product, when assembled, will look like the diagram in Figure 1 below the instructions.

1. Tape the pencil to the very edge of the table so that it is parallel with the edge.
2. If using erasers, stack the 5 erasers so that they are flat on top of each other, then wrap the stack vertically with tape to secure them. If using washers, make two stacks of ten, and wrap each stack vertically like with the erasers. Then, place the two stacks side-by-side, and tape them together horizontally.
3. Tape the stack of erasers/washers to the 0” end of the ruler.
4. Tape the ruler to the pencil at the 6” line so that the ruler is perpendicular to the pencil, the 12” end of the ruler extends past the edge of the table, and the erasers/washers are on the top side of the ruler. In order for the ruler to be able to pivot, position the tape so that it stretches over the ruler’s width and is parallel with the pencil. Then the ends of the tape that are on the pencil but not the ruler can be further secured.

Figure 1: A diagram of what the torque setup should look like.
Protocol

This is the protocol that the students will go through while performing the lab activity. Additional conceptual questions or calculations can be added by the instructor if desired.

Introductory Activity (optional)

This is an optional activity (not included on the worksheet) to help students connect the concept of torque to a real-world experience to help deepen their understanding of the material.

10. Find a door in the classroom.
11. From the “push” side of the door, open it using the door knob or by pushing the door furthest from the hinge.
12. Then try opening the door again, but push on the middle of the door.
13. Try again, but this time push closer to the hinge. Notice anything different about how difficult it is to open the door?

The instructor can offer as many different ways to open the door as they prefer.

Lab Activity

14. Students follow the worksheet directions in setting up the lab. The instructor draws diagram from Figure 1 above to clarify any confusion students may have.

15. Students zero the spring scale and take force measurements at different distances.

16. Students tape spring scale to the 9” line of the ruler then take force measurements at different angles, which they measure using Angle Meter (Android) or the level in the Measurement app (iPhone). To ensure students achieve the correct graph, there should be two measurements taken at angles less than 90°, one at 90°, and two greater than 90°.

Instructors should make sure that students are using the correct 0 point and include units in the brackets next to the data fields.

17. Conceptual Question 1
18. Conceptual Question 2

19. Students graph their data. One is force vs. distance, and the other is force vs. angle. Students should add titles to their graphs and labels to their axes.

The force vs. distance graph should look like 1/x and the force vs. angle graph should look like 1/sinθ.

20. Conceptual question 3
Conceptual Questions

These are the conceptual questions included in the worksheet accompanying the torque lab module, followed by the expected response for the question. The numbers below match with the numbers used in the Protocol above. Additional conceptual questions can be added by the instructor if desired.

1. Is torque constant in this experiment? Why?

   *Expected Response:* Yes because the force of gravity acting on the stack of washers/erasers is constant, the distance of this force to the fulcrum is constant, and the angle between the force and the ruler is constant.

2. Solve $\tau = Fl\sin\theta$ for force ($F$).

   *Expected Response:* $F = \tau /(lsin\theta)$. Students with a weak algebra background or who are not used to working with variables may need extra help.

3. Do the shapes of the graphs match this equation when $\theta = 90^\circ$ with a changing $l$? When $l$ is constant with a changing $\theta$?

   *Expected Response:* Yes, the force vs. distance graph looks like $1/l$ and the force vs. angle graph looks like $1/sin\theta$. 
E.3 Accompanying Worksheet

The worksheet, which begins on the next page, accompanies torque lab module setup. This worksheet has been revised from the worksheet in E.1 according to suggestions and survey results from the Society of Physics Students at WPI. The worksheet contains a protocol to take measurements and answer conceptual questions to help students deepen their understanding of torque. Furthermore, the worksheet is only on one page (double sided) to minimize printing costs and time to complete.
Torque Lab

Background:
As you have learned, forces acting on objects cause them to accelerate in a certain (linear) direction, but what is involved to give an object rotational acceleration (spinning or rotating) about an axis? These rotations can be attributed to torque, the formula for which is \( \tau = Fl\sin\theta \), where \( F \) is the force, \( l \) is the length between the pivot point and the force, and \( \theta \) is the angle between force and length. The purpose of this lab activity is to experimentally show that this equation above is true.

Materials:
- 12” ruler
- Smartphone with angle measuring app
- Spring scale
- Masking tape
- 20 stacked washers taped together
- A pencil

Procedure:
1. Tape the stack of washers to the 0” end of the ruler, then tape the pencil to the bottom side of the ruler at the 6” line. Next, tape the pencil to the edge of the table so it is parallel with the edge (the ruler should be perpendicular and hanging off the edge).
2. For the first set of measurements, keep the spring scale vertically perpendicular to the ruler (\( \theta = 90^\circ \)), and measure the force required to keep the ruler leveled at 5 different distances (and make sure your distances are recorded in meters!).
3. For the second set of measurements, tape the spring scale to the ruler at the 9” line. Then measure the force required to keep the ruler level at 5 different angles (two < 90°, one at 90°, and two > 90°)

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Questions:

1. Is torque constant in this experiment?

2. Solve $\tau = F_l \sin \theta$ for force.

3. Graph force vs. distance and force vs. angle.

4. Do the shapes of the graphs match this equation when $\theta = 90^\circ$ with a changing $l$? When $l$ is constant with a changing $\theta$?
Appendix F - Poster

The poster, which appears on the following page, was presented at the 2019 March Meeting of the American Physical Society, “a nonprofit membership organization working to advance the knowledge of physics.”² This project was part of the Undergraduate Poster Session at the Boston Convention and Exhibition Hall. To focus on the research done by the authors, the poster only touches on the future project design while explaining in more detail the results of the SPS event and its effects on the redesign of the lab modules.

² https://www.aps.org/