Implementation and Evaluation of a Seven-Week Pilot Studio Mechanics Course

An Interactive Qualifying Project

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of

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by

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Abstract

The feasibility of implementing a studio physics course at WPI was assessed by preparing for, implementing, and evaluating a pilot course. Studio physics provides an alternative, hands-on learning method for students. Using the Mechanics Baseline Test (MBT) and multiple feedback methods, students' qualitative and quantitative data were analyzed. The average resulting normalized gain of the class on the MBT was 18% (n=21). With continued support, studio physics has the potential to become an option for all students at WPI.

Authorship

This report was divided equally between both authors with the exception of the Results section. In this section, Sophia Leitzman authored the qualitative data portions while Joseph DePaolo-Boisvert created the quantitative data portions.

Acknowledgements

1. Introduction

The overall goal of this project was to determine if studio physics can be an effective teaching method at Worcester Polytechnic Institute (WPI). This Interactive Qualifying Project (IQP) team evaluated studio physics as a replacement or equivalent to the current lecture style introductory physics course by conducting a pilot course. Previous studies indicate that the use of interactive learning methods can increase the effectiveness of mechanics courses.[1,2,3] Although studio physics has been used effectively in higher education, studio physics at WPI is distinct because of three major factors: its seven-week course schedule, utilization of eScience Kits™, and use of a shared classroom space rather than having a dedicated studio space.

This project originated as an independent project by WPI's Professor Nancy A. Burnham PhD grant award from the 2016 Teaching Innovation Grants. The overall purpose of the grant was to "help the Physics Department [at WPI] evaluate [...] the merits of 'studio style' teaching, which eventually could be conducted in the planned active-learning space in the Foisie Innovation Studio. These changes aim to improve the learning of introductory physics for the two thousand students who enroll every year."[4]

The eScience Kits™ that were used for this project are the development of a relatively new company, eScienceLabs®.[5] Formed in 2007, the company seeks to bring a complete laboratory experience to online learners at a reasonable price. Although the company's website states they have served "more than 350 colleges and universities," a literature review and internet search, as well as communication attempts, failed to uncover publications about their usage. The eScience Kits™ were investigated and

some of the modules were utilized for portability of lab materials as well as to ensure that all groups of students have the same quality laboratory equipment.

Unlike other institutions, WPI does not have a classroom dedicated solely to the studio physics course, but instead will share a laboratory space with other courses once construction of a new building is complete. The laboratory equipment must be portable so that after each studio physics session the classroom can easily be returned to its original state, ready for use by any other course.

Overall, this IQP team was faced with implementing a studio physics course that provided an authentic and interactive experience in short-term classes and a space not dedicated only to the studio course while utilizing portable laboratory equipment.

The short-term objectives of this project were those that aimed to be completed over the duration of the pilot course. Content objectives were to help students learn the fundamental principles behind kinematics, force, momentum, energy, and rotational motion, as well as show students how to apply those basic principles to solving physics problems in Cartesian coordinates using geometry, trigonometry, algebra, and calculus. Another objective was to give students an understanding of the correlation between theory and laboratory experiments so that they are able to predict and analyze translational and rotational motion. The final objective was to attempt to maximize student involvement and contact with instructors and other students through varied approaches and group work so the students were comfortable asking questions and discussing topics.

Student scores on the Mechanics Baseline Test (MBT), developed by David Hestenes and Malcolm Wells[6], as well as students' qualitative feedback, were the basis

of the evaluation of the course. Using the data collected, the feasibility for WPI to incorporate a studio course into its curriculum was evaluated. It may be possible to incorporate studio physics as a permanent class or even replace the traditional lecture style class currently used. Nearly every student at WPI takes introductory mechanics as well as introductory electricity and magnetism (E&M). Implementing studio physics at WPI has the potential to affect up to nearly two-thousand enrolled students on a yearly basis.

This report will contain a literature review of installations of studio physics at other schools and discuss the context of this IQP team's project. The methods used will be presented and the results examined to determine the successfulness of the pilot course as well as the feasibility to include studio physics in the curriculum at WPI.

2. Literature Review

In this section, background on studio physics, group problem-solving, electronic clickers, smartphone usage in the classroom, and potential risks of studio physics will be discussed. Theories of cognitive development on which studio physics and its activities are established also shall be discussed.

2.1 Studio Physics

Interactive learning in a physics course (also referred to as studio physics) was first implemented at Rensselaer Polytechnic Institute (RPI) in 1993.[7] Since then, studio courses have been implemented in approximately one-hundred-fifty other schools.[8] The main purpose of studio physics is to make introductory physics more student-centered. Contrary to a lecture hall, where students sit facing the instructor, students in a studio classroom are organized into groups facing one another at tables.[9] The table model allows instructors and teaching assistants to circulate through the room and provide attention to more students or student groups individually. In general, a typical day in a studio classroom consists of a brief lecture of a topic (possibly with clicker questions to keep students involved), group problems on that topic, and a laboratory activity or experiment involving that topic.

On a theoretical basis, active learning is a form of informal cooperative learning that facilitates the engagement of students with the class material and with other students.[10] Informal cooperative learning consists of students working together to achieve a joint learning goal in temporary groups while also ensuring that students help each other clear up minor misconceptions and gaps in understanding. Forming informal cooperative learning groups allows the instructor a chance to listen in on student

discussions and identify any misunderstandings in the class content. "The greatest single challenge to SMET [Science, Mathematics, Engineering, and Technology] pedagogical reform remains the problem of whether and how large classes can be infused with more active and interactive learning methods" (p. 87).[11]

The theories behind studio physics are largely due to research conducted by Jean Piaget and Lev Vygotsky.[12] Piaget's theory suggested that people must adapt to their environment, wherein the desired equilibrium between themselves and their external surroundings is reached by assimilation. This theory can be used for educational purposes by allowing individual students to construct their knowledge after the instructor has provided the foundation for this knowledge. Vygotsky's theory focuses on social interaction and how it can be used effectively in student learning. This can be brought into the classroom using active learning methods where a task is provided to students in small groups and the instructor provides assistance to the students until they are successfully able to complete the task. A combination of both Piaget and Vygotsky's theories would theoretically maximize student learning.

Studio physics has been associated with many benefits in the past, such as greater student involvement and engagement in activities[13] rather than just "passive listening" as well as an increase in student motivation.[14] Maintaining interest and attention is easily done with studio-style courses in that students find various activities useful for breaking up time and keeping them alert.[15] Students are more likely to be motivated for this type of course because there is less of an emphasis on didactic information being retained and more of a focus on application of content learned.

Additionally, studio physics provides students with immediate feedback from their instructor(s), as well as increases retention of information.[3,16]

A study conducted by the physics department of the University of British Columbia reported that in a large classroom setting, student engagement increased by 40% when "research based instructional methods" (active learning strategies) were introduced.[17] Another study conducted at the University of Washington found that the use of active learning strategies, such as clicker questions, increased student course attendance. This study also posited that higher exam scores may have been a result of either active learning strategies themselves, or simply increased student attendance.[18]

Theory and research suggest that learners can and will be motivated to explore their area of study if the instructional system is well-designed and learners are adequately prepared.[14] When students are motivated to learn, they challenge themselves. They focus on the path to the correct answer, rather than simply obtaining it.[19] A study conducted at the Torbali Technical School of Higher Education concluded that interactive learning methods, such as critical thinking skills and peer learning, had positive effects on student motivation.[20]

Further studies conclude that active learning strategies promote student retention of information. Overall, students tend to remember concepts from actively being engaged in an exercise, rather than passively listening in a lecture course.[21] Student outcomes of active learning include higher academic achievement, increased comprehension and retention, and development of higher level thinking skills.[22]

A field experiment performed by Kerri L. Kettle and Gerald Häubl at the University of Alberta concluded that students who are expecting more rapid feedback

from their instructors perform better than those who are expecting feedback later.[23] This experiment, performed on 501 students, tested the effectiveness of immediate feedback by having the instructor vary their response time to certain groups of students. Students were tasked with giving individual presentations for a college course and were randomly assigned to three different feedback-rate groups: receiving feedback one, eight, or fifteen days prior to their presentation. These groupings resulted in a performance difference of 0.56 standard deviations between the sooner and later feedback rates.

2.2 Group Problem-Solving

An experiment carried out by Patricia Heller and Mark Hollabaugh to "adapt the technique of cooperative grouping to physics problem solving" took place at two different universities: the University of Minnesota and Normandale Community College.[24] The experimenters found that working in groups is a very effective teaching method for both an introductory physics course as well as a sophomore-level modern physics course. Student questionnaire data showed that 72% agreed with the statement, "The discussion with my group helped me understand the course material" while only 11% disagreed with the statement.

A separate experiment by Patricia Heller, Ronald Keith, and Scott Anderson investigated the differences between problem-solving individually versus working in groups.[25] Their study concluded that working in groups greatly benefitted students; they were able to reach better solutions because "In well-functioning cooperative groups, students can share conceptual and procedural knowledge and argument roles, and request clarification, justification, and elaboration from one another…" (pg 635).

Additionally, when the group problem-solving experimental section was compared to the traditional section where students worked independently, it was found that the students in the experimental group attained significantly higher scores.

2.3 Clickers

A study by Jane E. Caldwell at West Virginia University (WVU) discussed the typical goals of Audience Response Systems (Clickers) as well as the outcomes of their use.[26] A clicker is a small transmitter that is most commonly used to poll student responses to a multiple choice question. However, modern clickers include a 10-digit keypad, allowing for numerical input. When linked to grades, the use of clickers was found to increase class attendance and participation, especially if it was a daily activity.[27] Physics instructors report that when clicker scores account for 15% or more of the course grade, attendance levels rose to 80-90%, preparation for quizzes increased, and students were noticeably more alert in class.[28] Students made comments such as "I like clickers [because] it helps in the learning experience [because] you can talk out some problems with others" (pg 15) and "I really enjoyed using the clickers. It did help reinforce the material and provided a nice break in lecture and a chance to make sure you understand the material" (pg 15).[26] Another study performed at the University of Massachusetts compared the usage of clickers between two undergraduate courses as well as a graduate-level course.[29] The authors found value in being able to immediately be aware of what their students did and did not understand and added that the usage of clickers was found to "add value to teaching and learning" (pg 18).

2.4 Smartphones

Recently, software compatible with cellular phones is available for download to run physics experiments using the cellular phone's various sensory devices, such as gyroscopes and accelerometers. A study conducted at the University of Valladolid[30] researched the use of smartphones in physics teaching. The study found that students had very positive responses to the use of smartphones as measurement devices, and would use them again in other classes. Additionally, the study concluded that the use of smartphones increased student involvement and engagement, leading to a reduced number of dropouts.

Another study from the University of Kaiserslautern[31] assessed the accuracy of smartphones as measurement devices for various physics experiments. Experiments concerning acceleration by gravity, free-fall, acoustics, and energy loss on impact were all tested. The study concluded that smartphones "can be used to enhance physics classroom education in many ways, especially in order to perform experiments when used as an experimental tool."

2.5 Risks

There are two main types of risks associated with implementing studio physics.[32,33] The first type of risk is for students; there is a possibility that the students will not be active participants in the class, leading to them to learn an insufficient amount of the content. Some students may not have the ability to use higher thinking skills, a necessity for this course style, which could potentially affect their overall engagement for the class.

The second type of risk is for faculty members. Faculty may not feel confident enough to run this type of course or feel like they do not have control of the class due to not having any experience in this area. If they have not seen someone run a studio course before, professors may not feel confident in their choices or feel like they simply do not know how to go about running the course, causing them to run the studio class poorly.[32]

2.6 Summary

After reviewing the topics of studio physics, group-problem solving, clickers, smartphones, and the risks of studio physics, the literature provided the basis of the structure of the pilot course. Having never conducted studio physics at WPI, the authors and instructor of the course relied on the literature to determine the methods and benefits of studio physics.

3. Context

The academic calendar at WPI follows a quarterly schedule known as A, B, C and D Terms.[34] Each term is seven weeks in length and students take three courses concurrently during a term. The seven-week course schedule allows students to focus intensely on the three topic areas studied. However, despite the intense pace, most seven-week courses cover only about two-thirds of the material in a fourteen-week course.[35]

The textbook used for this course was Young and Freedman, *University Physics,* 14th Edition ©2016, the same text used by the traditional introductory physics courses at WPI. Students also completed homework and preparatory work in Mastering Physics[36], the online homework portal associated with the text.

The pilot studio course consisted of twenty-four students who self-selected themselves into the course. Introductory physics is a required course for nearly every major at WPI, with the majority of students enrolling in their freshman year. The pilot course had twenty-four available seats for students and, conveniently, twenty-four registered.

Of the twenty-four students, there were eleven male (45.8%) and thirteen female (54.2%) students - a considerable difference to WPI's overall male-to-female ratio of 68% male to 32% female.[37] The class consisted mainly of first year students - the distribution was fifteen freshman (62.5%), seven sophomores (29.2%), one junior (4.25%), and one senior (4.25%) by credits.

The room used for the studio course was set so that the whiteboard was in the front of the room and the students sat around rectangular lab benches in a traditional

physics laboratory. To the right of the whiteboard was a projection screen used for clicker questions and class activities. There were twelve "stations" that the students were randomly assigned to at the beginning of each studio session for the first half of the course. The stations were designed more for group work than lecturing; not every station faced the front of the classroom, but students were free to move about the room to allow them to face the board and take notes effectively (see Figure 1). Most laboratory experiments and problem solving on portable whiteboards were conducted in pairs. However, pairs of students could easily converse with up to three other pairs adjacent to them to discuss the work. Both the layout of the classroom and the initial tactic of random assigned seating aimed at building class chemistry so students would feel more comfortable discussing material and moving about the room.

Figure 1 - A picture of the proto-studio classroom, which was an introductory physics laboratory room. Students were organized into twelve pairs, each pair at a station with a computer. The students worked with their random partner for problem solving and laboratory activities. The classroom space also allowed for larger groups of four to form for the purpose of working through difficult problems or labs.

During a typical week, the class met on Tuesday and Friday for two-hour studio sessions and on Wednesday for a quiz period of one hour. All of these formally scheduled hours took place with the professor instructing the course. In comparison,

the traditional lecture courses offered at WPI meet for one-hour lectures on Mondays, Wednesdays, and Fridays with the primary course instructor. The traditional lecture course also meets for one hour on Tuesdays and Thursdays for a recitation period that may or may not be led by the primary instructor, and for an additional hour on Tuesdays and Thursdays for a lab period that is led by a graduate student. Therefore, in a standard week, students enrolled in the studio course had fewer formally scheduled class hours, but more scheduled hours with the primary course instructor.

4. Project Implementation

This IQP took place over the course of three terms at WPI (B, C, and D Terms) with each term representing a different phase of the project. B-Term was the preparation period, mostly consisting of testing laboratory experiments that were included in the eScience Kits™, planning the evaluation, and researching previous studies of studio physics at other institutions. C-Term was the implementation and data collection period when the studio course was run. D-Term was the analysis period where data were evaluated for effectiveness of meeting the project's short- and long-term goals.

During B-Term, weekly meetings with the project advisor, Professor Nancy A. Burnham PhD, were organized to discuss the tested laboratory experiments and the literature found during that week. Over the course of B-Term, two laboratories were tested each week and evaluated for their potential as possible labs to conduct during the pilot course (see reports in Appendix A). The laboratory experiments were evaluated based on their ease of assembly and disassembly, their educational value, and their time consumption. Those experiments that seemed unhelpful or confusing were dismissed while better experiments were altered to suit the exact needs and learning objectives of the course. Additionally, reports of studio installments at other schools were researched and discussed in the weekly meetings. The research of other institutions aided in deciding which segments would make up the studio session.

During C-Term, the pilot studio course was initiated. Classes took place for two hours at a time on Tuesdays and Fridays and included a one-hour quiz or recitation period on Wednesdays. On average, students at WPI are expected to put fifteen to

seventeen hours of work per week into each of their three courses. In an effort to give students the proper amount of work to aid them in learning the material, students were assigned homework problems (four hours per week), worksheets (two hours per week), and preparatory work (two hours per week). The workload was designed to take the average student thirteen hours per week, allowing for two to three additional hours of study time. While the class was in session, the authors recorded the amount of time spent on each activity, as depicted in Figure 2.

The studio time shown in Figure 2 is divided into the following categories: lecture, challenge problems, clicker questions, whiteboard work, group lab work, administrative, and miscellaneous. The lecture component typically occurred at the start of each studio session and lasted between fifteen to twenty minutes. As a subset of the lectures, challenge problems were led by the professor while students were free to ask questions as they were being walked through the problem. Clicker questions would also occur during the lectures where students would use their electronic clickers to individually respond to multiple-choice questions provided by the instructor. After responding, students were provided the correct answer and were given a chance to discuss with others around them. Whiteboard work refers to students working on personal whiteboards in pairs to solve practice problems. Each studio session would have time for group lab work where the students would continue to work in pairs on the eScience-altered labs or labs of the instructor's own creation. Administrative consisted of activities such as providing feedback, reviewing the schedule for the day, or administering the feedback forms while miscellaneous referred to the distribution and execution of the MBT.
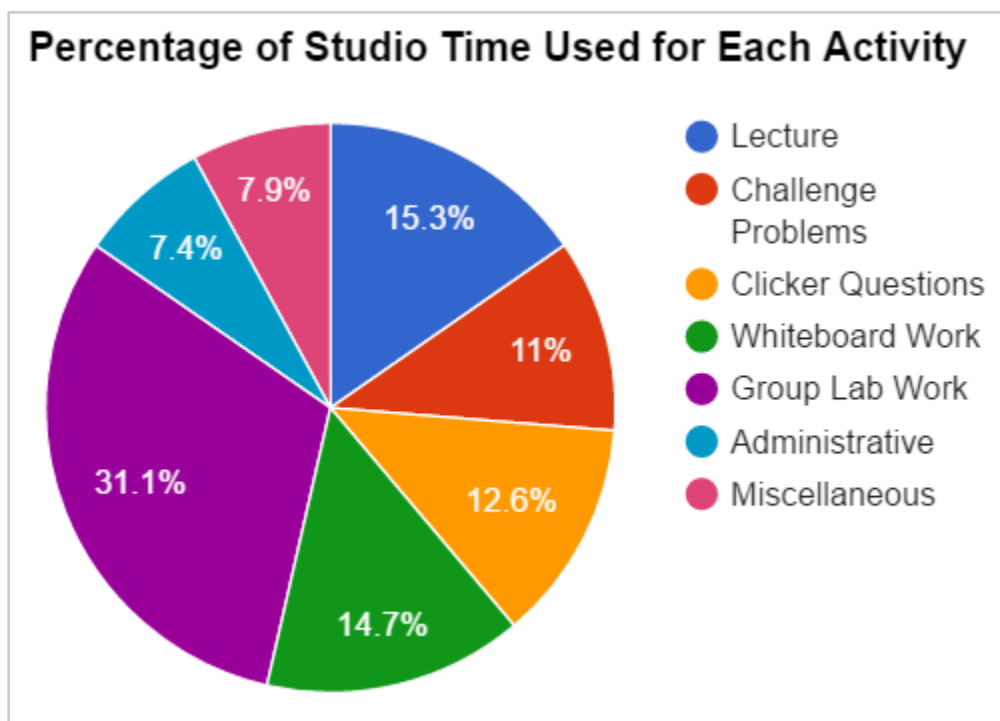
Figure 2 - A pie chart depicting the average amount of time spent on activities in the classroom. In this chart, the six quizzing periods of one hour each are excluded. The miscellaneous category is largely made up of the administration of the MBT, which took an hour for each administration. The chart is comprised of a total of twenty-nine hours of formally scheduled student-instructor interaction time.

Laboratories were conducted using materials from the eScience Kits™. However, few sets of instructions were taken from the kits, but only after being heavily modified. A lack of clarity in some of the eScience Kits™ directions forced many of the laboratory assignment instructions to be of the instructor's creation. However, the assignments still utilized the kit's materials (see Appendix B).

During the course, it was common for students to use their cellphones to record an experiment or demonstration with a slow-motion camera. They could then go back and watch their videos to obtain data about an experiment that would have been difficult to track in real time.

Both authors of this report acted as teaching assistants (TA's) for the pilot course. The role of the TA's was to circulate the room and assist students whenever

necessary as well as to set up and disassemble the lab equipment. Furthermore, the TA's were responsible for the grading of student worksheets and laboratory reports.

4.1 Evaluation

At the beginning and end of the course, students took the MBT for the purpose of calculating their normalized gain. Their scores on the MBT did not have a significant impact on their overall grade in the course. The MBT questions were all worth a clicker question's points, providing incentive for students to do well, but having no real affect on their grade. The course's grading scheme used included quizzing (60%, six quizzes at 10% value), Mastering Physics preparatory work (12%), Mastering Physics homework (20%), laboratory worksheets (6%), and clicker questions (2%). The grading scale was designed to make quizzing the primary method of evaluating students and to also heavily encourage the completion of prep work and homework, making the use of class time more efficient.

The quizzes used in the course were problem solving based, unlike the MBT, which is multiple choice and conceptually based. Each quiz consisted of three multi-part problems, each graded out of five points. Generally, the problem that the students performed least well on was made into a bonus question. Using this method, students did not know which question will be the bonus. Thus, the quiz was graded out of ten points, with up to fifteen possible.

At the end of each studio session, student feedback was collected using index cards where students individually wrote what they thought were the most important, most helpful, and least helpful activities during that session. Larger scale feedback was collected at the middle and end of the course.

During D-Term, the students' performance in the pilot studio course was determined by measuring normalized gains on the MBT. Each student's gain was analyzed using their scores on the MBT from the beginning of the term (PreScore) versus the end of the term (PostScore). The normalized gain was calculated using Equation 1, where PreScore and PostScore are both represented by percentages.

$$Normalized\ Gain\ =\ (PostScore\ -\ PreScore)\ /\ (100\ -\ PreScore) \qquad (1)$$

Using this formula, each student's gain was calculated for the MBT, as well as specific topic areas within the MBT.

Along with the MBT data, the index cards, the midterm feedback forms and final feedback forms provided useful qualitative data when looking to find the students' opinions on the helpfulness of the course. The index cards were an integral measure of the day-to-day activities of the studio sessions and the students' comments were taken into consideration.

The midterm feedback form included items for which the students rated the helpfulness of each activity for learning the course material. The activities included in the form were: mini-lectures, clicker questions, lab activities, challenge problems, and whiteboard problems. Students were asked to rate each of the activities as "very helpful," "helpful," "neither helpful nor unhelpful," "unhelpful," or "very unhelpful." Students also completed a final feedback form, which is standard procedure for all courses at WPI (see Appendix C). An additional three questions were added to the final feedback form.

5. Results

In this chapter, the authors will discuss implementation results from the index cards, midterm feedback form, and final feedback form as well as knowledge-based results provided by the utilization of the Mechanics Baseline Test.

5.1 Implementation Results

Over the course of the term, the index card feedback was utilized as a method of communicating with students and receiving feedback about the class on a day-to-day basis. If there was a general consensus that students did not like an aspect of the course, it was considered and possibly changed. Some important changes include the homework deadline, which was initially set to six o'clock in the evening the day before a studio session and was later changed to midnight. The preparatory work, previously due at eight o'clock in the morning before the start of the studio session at nine o'clock in the morning, was then swapped with the homework. This switch ensured that students prioritized preparatory work over homework. Lastly, midway through the course, the randomized seating was eliminated and students could sit and work with whomever they pleased.

The index card feedback data frequently produced mixed responses from students about the classroom activities. Based on this feedback, the instructors concluded that, although each student did not find every activity helpful, every student found something helpful. Every student in the classroom had at least one activity that they liked and was helpful to their learning.

Aside from being a useful communication tool, the index cards that were filled out at the end of every class were also useful measures of the helpfulness of the various

class activities. Looking at all of the index cards together, there is a good distribution of general positive comments with more precisely directed negative comments. On a day-to-day basis, the students found the lab activities (receiving 27.5% of all positive remarks) to be most helpful. The next most helpful activities were the mini-lectures and group problem solving sessions, receiving 22.7% and 19.1% of all positive comments respectively.   The challenge problems elicited a relatively neutral response from the students, receiving 13.2% of all positive remarks, but also 11.7% of all negative remarks. The clicker questions were the least helpful activity for the students — 31.4% of negative comments were directed at the daily clicker questions, which only received 9.5% of positive remarks. Additionally, although the laboratory experiments received the highest percentage of positive remarks (27.5%), the labs also were the attention of 28.7% of negative remarks. Group problem solving and mini-lectures received only 8% and 5.3% of all negative remarks respectively.
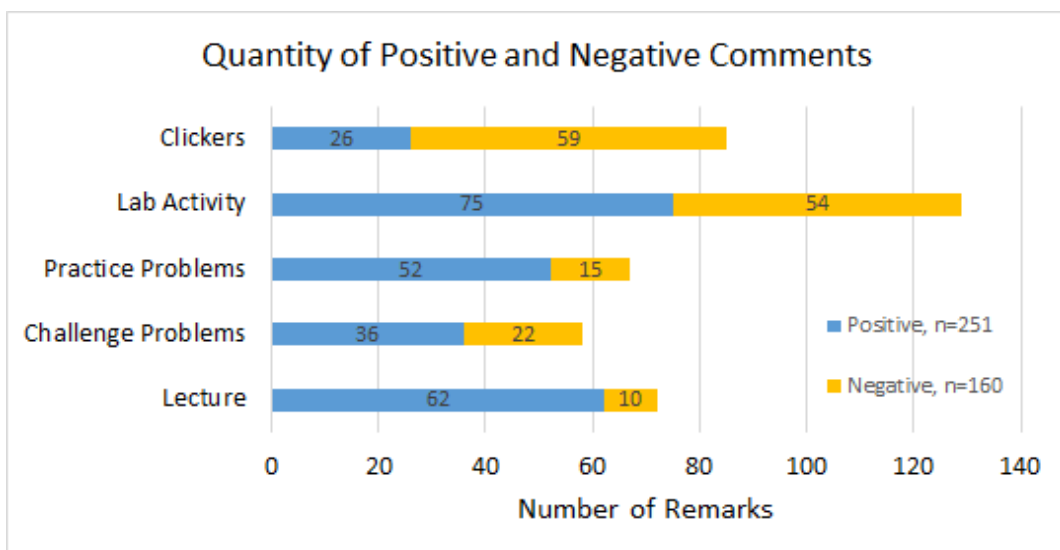
Figure 3 - The distribution of positive and negative remarks on each class activity.   The length of the bars shows the number of comments made about each activity.   Lab activities, for example, had the highest number of comments, but was relatively neutrally received.   For the five activities shown, a total of 251 positive comments and 160 negative comments were received.   Throughout the term, there were 32 blank index cards collected.

Similar to the index card responses, student feedback received specifically from the midterm feedback form (n=22, 92%) showed that they found mini-lectures the most helpful, followed by the instructor's challenge problems (see Figure 4). "Group problems" was the only activity to receive a rating of "very unhelpful", which can be attributed to the student possibly being paired with a partner whose physics knowledge was weaker than what they needed. While one student gave group problems a rating of "very unhelpful", the activity was rated "helpful" by 54.5% of students.

The activity receiving the highest helpfulness rating was mini-lectures. Over half (54.5%) of the students rated it as "very helpful" and 45.5% rated it as "helpful." Instructor problems or challenge problems was the next most highly rated activity. Over a third (38.1%) of the students rated it as "very helpful" and 42.9% rated it as "helpful." While lab activities were a highlight of the course, this comment was rated "very helpful" by 13.6% of students. An additional 50% of students rated lab activities as "helpful." Clicker questions were rated as "very helpful" by 22.7% of students and "helpful" by 45.5% of students. However, one student (4.5%) rated them as "unhelpful". As for group problems, 54.5% of students rated them as "helpful," whereas 13.6% of students rated them as either "unhelpful" or "very unhelpful".

As an overview, the activities in Figure 4 received ratings of "very helpful" and "helpful" totaling to the percentages as follows:

- Group Problems: 72.7%
- Instructor Problems: 81.0%
- Lab Activities: 63.6%
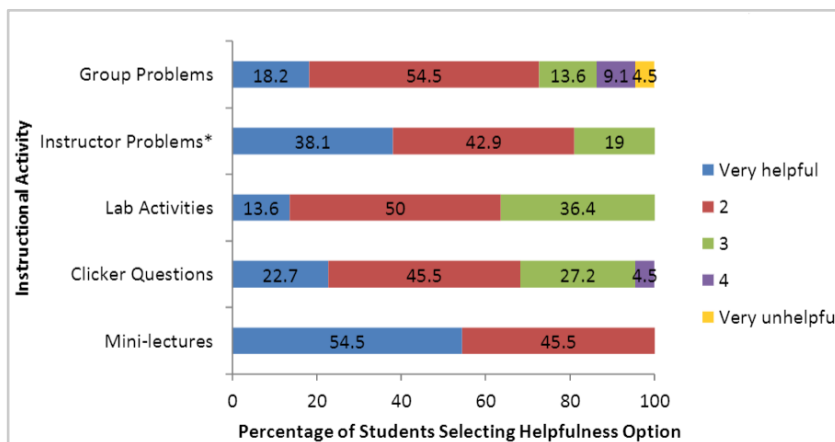- Clicker Questions: 68.2%
- Mini-Lectures: 100%

Figure 4 - Helpfulness of in-class activities rated using the midterm feedback form.
*One student did not provide a ranking for this activity.

The final feedback form, distributed on the last day of class, included items for which students rated the various aspects of course instruction and the instructor's teaching on a scale of 1 (very poor) to 5 (excellent). The authors utilized the students' overall rating of the course and a question pertaining to the relation of quizzes to the course material covered (See Appendix C). Additionally, three free-response questions at the end of the form were reviewed. Many of the questions provided by the final feedback form were not found to be useful because they were based on the quality of the instructor's teaching and course work, rather than the helpfulness or lack thereof for the course's activities.

There were twenty-one students present the day the final feedback form was distributed. The average ranking by students for the overall quality of the course was a 4.0 ± 0.8 out of 5.0 (See Appendix C). When asked, "Should we continue studio classes?" all nineteen students who responded to the question said studio courses should continue to be offered at WPI.

Of the twenty-four students in the course, twenty-one took both the pre and post MBT. These twenty-one students reported an average of 18% normalized gain on the MBT, with the lowest -11% and the greatest 64%. As seen in Figure 5, three students (14.3%) received a negative gain. Three more students (14.3%) made zero gain. Eight students (38.1%) had positive gain less than 25%. Six (28.6%) students had positive gain between 25% and 50%. And one student (4.7%) achieved greater than 50% gain.
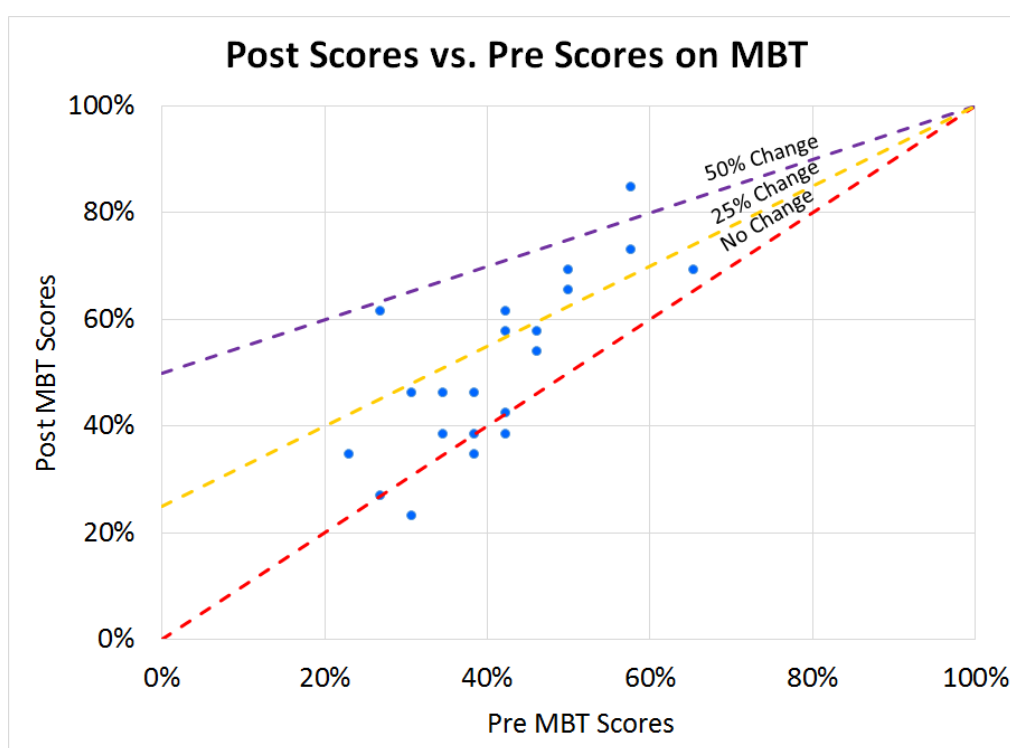
Figure 5 - A graph of each student's overall MBT post score percent plotted against their own pre score percent. Select percent changes are indicated by lines on the graph.

Other universities who have implemented studio physics have reported gains ranging between 17%[38] and 39%[39]. In 2006, Georgia Southern University, reported gains of 17% and 30% using the Force Concept Inventory (FCI) for their first and

second iterations of a studio course, respectively.[38] Also using the FCI, Ithaca College

reported a gain of 23% in their first year and 28% in their second.[9] When RPI first

began studio physics, they reported a gain of 18% on the FCI and a gain of 21% on the

Force-Motion Concept Evaluation (FMCE).[7]
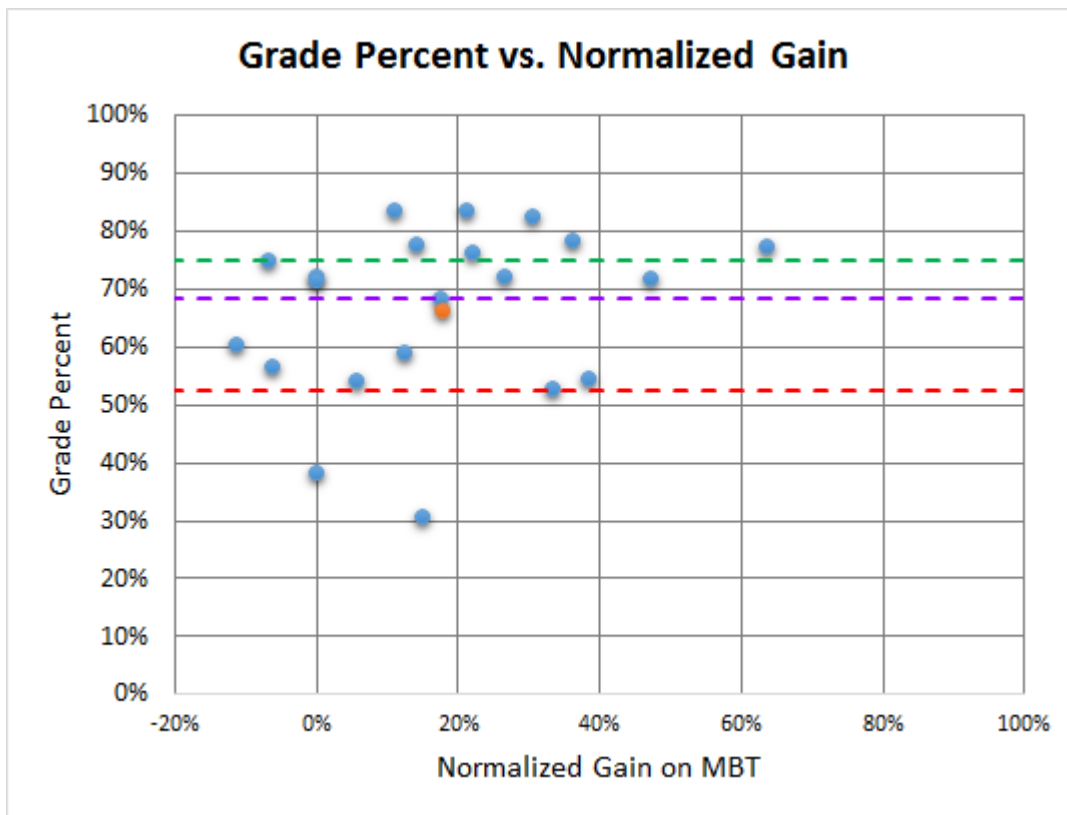
Figure 6 - Students' final grade percent plotted against their normalized gain on the MBT. Each blue dot represents a student (n=21). The orange dot represents the average grade of these twenty-one students (66%), plotted against the average gain (18%). Additionally, the horizontal lines represent the grade cutoffs. Students at or above the green line received an A, those at or above the yellow line received a B, those at or above the red line received a C, and those below the red line failed the course.
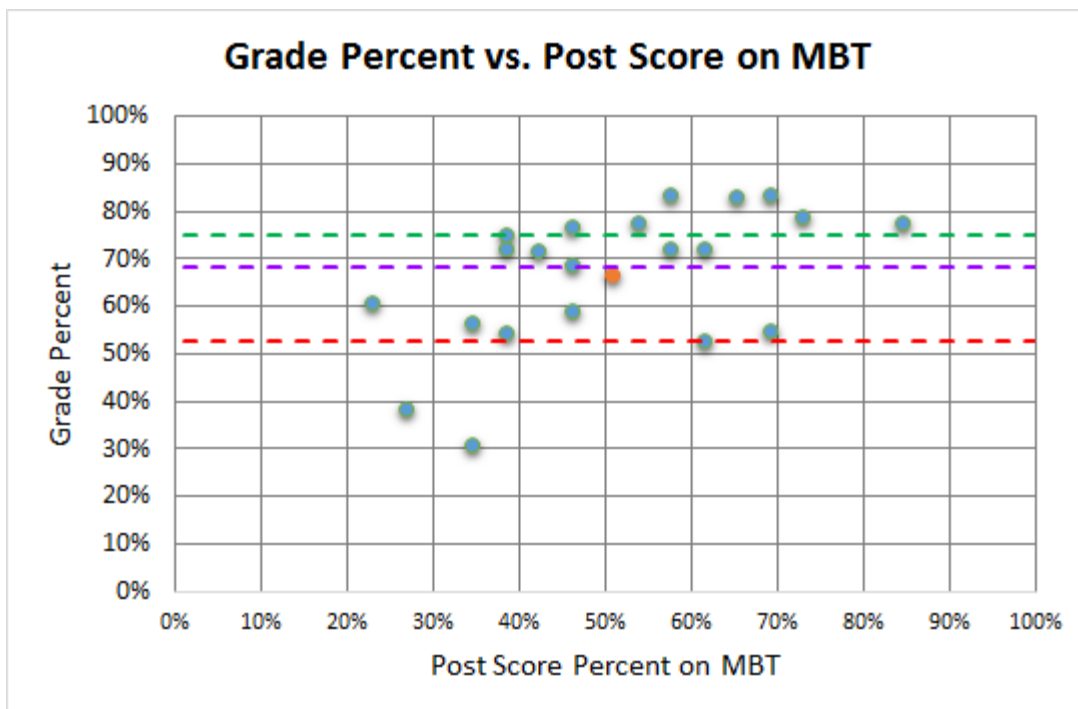
Figure 7 - Students' final grade percent plotted against their score percent on the MBT. Each blue dot represents a student (n=21). The orange dot represents the average grade of these twenty-one students (66%), plotted against the average score percent (51%). This figure depicts a very similar correlation between grade and post-score as did the graph of grade against gain on the MBT. The same grade cutoffs as in figure 6 are included. The linear correlation between grade percent and post score percent is very weak, and the difference is not statistically significant (r=0.536).

As seen in Figures 6 and 7, there is not much evidence to support any overall trend in the grade percent vs. gain or in grade percent vs. post MBT score. However, it is notable that most students who performed better than average on the MBT performed better than average in the course. No student who performed better than average on the MBT failed the course.

The MBT was also broken up into topic areas and student gains in each topic area were calculated. The MBT contains 26 questions, including questions in the topic areas of Kinematics (9 questions), Circular Motion (4 questions), Newton's Laws (8 questions), Energy (2 questions), and Momentum (3 questions). Figure 8 depicts the

students' average score percentages for each question on the MBT, divided by topic. Students made very significant improvement in the topic of energy. Students made an expected amount of improvement in the topics of kinematics and momentum. The areas of Newton's laws and circular motion proved confusing for the students. Several of these questions were actually answered incorrectly on the posttest, suggesting that the content of these questions were either not clarified in the course or were not emphasized enough to eliminate confusion on the topic.

5.3 Summary

In summary, mini-lectures and group problems were found to be the most helpful activities. This is supported by the index and midterm feedback. Lab activities had potential to be very helpful, but experienced pitfalls such as unclear instructions, causing the students to have mixed feelings about them. The average gain on the MBT was 18%, ranging from -11% to 64%, which is consistent with the average gain reported by other schools in their first iteration of studio physics.
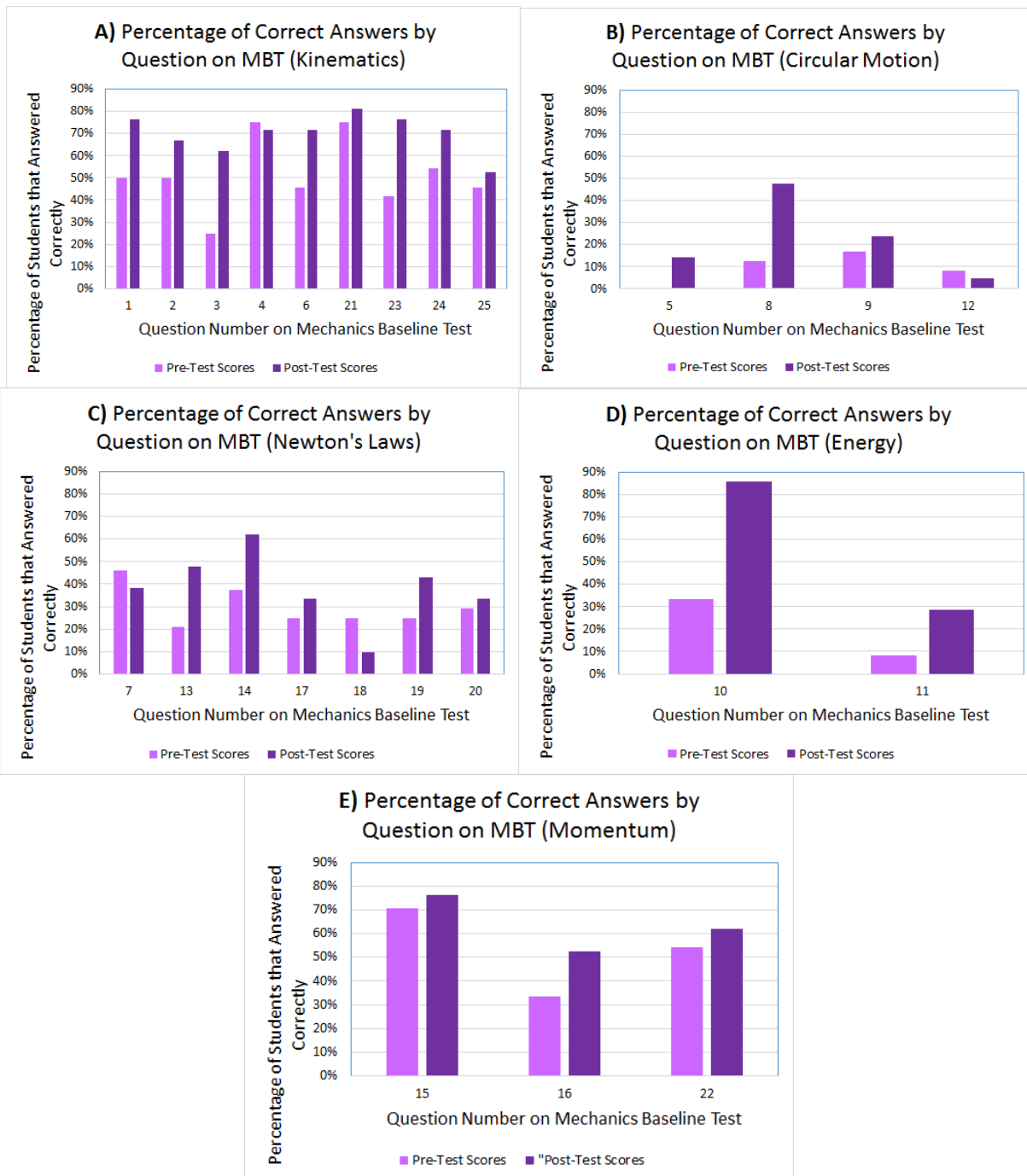
Figure 8 - A question by question analysis of question correctness on the MBT. The percentage of students (n=21) who correctly answered a question on the pretest and posttest is plotted for each question. The question topics are (a) Kinematics (1-4, 6, 21, 23-25), (b) Circular Motion (5, 8, 9, 12), (c) Newton's Laws (7, 13, 14, 17-20, 26), (d) Energy (10, 11), and (e) Momentum (15, 16, 22)

6. Discussion

In this section, the authors' thoughts on the use of the normalized gain equation, the MBT, self-selection into the course, and laboratory experiments will be reviewed. Additionally, a SWOT analysis will be provided followed by the authors' overall thoughts on the course.

6.1 The Normalized Gain Equation

The normalized gain equation is a useful method for measuring student improvement, but has a couple of interesting quirks. First, if a student gets a 100% on the pretest for any set of data, that student will have an undefined gain. The only time a student has defined gain with a 100% pretest is when a 100% is scored on the posttest, in which instance the student will have zero gain. If a student receives a 100% on the posttest, their gain will be equal to 1 for any pretest score other than 100%.

Second, the normalized gain equation has the potential for a bizarre range of outputs. Unless bonus points are provided, the normalized gain is never more than one. However, the normalized gain can be less than -1, should a student do very well on the pretest and very poorly on the posttest. Their normalized gain, in this instance, will be much less than zero. There were instances where students received a negative gain for a set of data, and one instance where a student received negative gain lower than -1.

6.2 Interesting Results and Thoughts on the MBT

The first time the students took the MBT, the average grade was (41 ± 11)% correct whereas the second time the students took the MBT, their average grade was (51 ± 16)% correct. Based on the pretest average, it is unfair to make an assumption

that students had no prior knowledge of physics when starting the course. If this assumption was made, the students would have been expected to choose answers randomly on the pretest and the average pretest grade would have been expected to be 20%. This percentage is expected because all questions on the MBT are five-answer multiple choice, so if every student answers randomly, the result would be 20%. This grade is two standard deviations away from their actual average grade, falsifying any assumption that the students have no prior knowledge of physics. The average percent correct grade improved by one standard deviation for the posttest, but the distribution was less precise. Students performed at a more similar level for the pretest compared to the posttest.

The most reasonable theory to explain this phenomenon is that students had little to no prior knowledge of physics and used common sense to try and solve the problems originally. This is supported by the question by question analysis of the MBT. Students made some gain in areas such as kinematics, which is relatively straight-forward and solvable using common sense. More difficult topics such as circular motion and energy were improved significantly between the two tests.

The students tested better on average the second time they took the MBT, but with a higher standard deviation of grades. The increased distribution of grades indicates that each student did not improve by the same amount, but rather, that some students received the instructional style very well and others did not. While the pretest is an assessment of the students' prior physics knowledge, the posttest is a measure of the success of the course in teaching each student. One reason for the greater distribution of grades on the posttest may be due to an inability to cater to each

student's learning needs. Several students commented after the course was over that the course felt unorganized, which caused them to learn the material less effectively. As a first year offering of studio physics, there were changes over the course of the term to the course structure, and the class was not completely optimized because it had never been tested at WPI before.

6.3 Self-Selection into the Course

College-level mechanics can be very intimidating for students; some students, when selecting the studio course, may have believed the studio style to potentially be easier than the traditional lecture style. Another reason for self-selection into this course could be student preferences for hands-on learning and/or smaller class sizes.

6.4 Student Quizzing

The quizzes were purposefully made different than the MBT. Although the MBT is a conceptually based test and it is important for students to be able to solve conceptual problems, problem-solving was stressed in the quizzes. Students must be able to solve physics problems to be successful in many of the disciplines offered at WPI. However, conceptual problems were presented to the students in homework, preparatory work, and clicker questions in class. Thus, the course was not taught to the MBT, in fact, the opposite is true - the course was taught to emphasize problem solving abilities.

The course professor found the quiz results to be generally disappointing. In some cases, when students scored extremely poorly on a question, it was changed into a bonus question and an altered version of the same question was put on the next quiz. However, students showed little to no improvement on the question the second time it

was presented to them. There are multiple, equally probable reasons that students did not perform well the second time they saw a question. The practice of having six quizzes may have not emphasized retention of information and students may have just learned what they needed to week to week and forgotten the previous week. Additionally, having weekly quizzes may have been too frequent of a testing period for an introductory mechanics course, and students may not have had time to review the previous week's material as they prepared for the next quiz.

6.5 Students' Quiz Feedback

One question on the final feedback form yielded a particularly wide distribution of responses. "Exams and evaluations were good measures of the materials covered." However, it is likely that the students who disagreed with this statement simply did not apply themselves in preparing for the quizzes. Much of the class time emphasized problem solving, which was the basis of the quiz. At least one "challenge problem" was presented every class period and solved by the instructor. It was very common for the quizzes to be similar to the challenge problems, or even the same problem with different numbers. Additionally, the previous week's bonus question was also included on the quizzes, again, a problem that the students had seen before with different numbers. Although student feedback is valuable in this endeavor, the instructors must disagree— the quizzes were often direct reflections of material presented in class. However, the discrepancy bears consideration; it is possible students may have lacked enough conceptual knowledge to be able to solve problems.

6.6 Laboratory Experiments' Drawbacks

One problem the authors ran into with the implementation of the labs was that it would take the students much longer to perform than originally planned. Some labs would take the authors and professor five to ten minutes to complete while the students would spend forty-five minutes on the same activity, even with the instructions trimmed to the learning objectives of the course. Often, some groups were left waiting for others to finish data collection. Conversely, slower groups did not always have time for data processing, as it took them the majority of the lab time just to acquire data. This occurrence would cause the schedule for the session to be changed on the fly, most often leaving less time for whiteboard practice problems.

6.7 SWOT Analysis

Table 1 - Depicts the strengths, weaknesses, opportunities, and threats (SWOT analysis) for the pilot studio course. A SWOT analysis is a useful framework for summarizing the internal strengths and weaknesses as well as the external opportunities and threats.

Strengths:	**Weaknesses:**
● Hands on ● Interesting ● Interactive ● Small class size	● Lab instructions not always clear ● Students requested more examples
Opportunities:	**Threats:**
● Greater relationship between homework and quizzes ● More mini-lectures ● Instruction before individual work ● More practice time	● Sharing physical space ● Maintaining small class size

The analysis shown in Table 1 summarizes important findings and qualities of the studio course. While students appreciated hands-on and interactive activities, the lab instructions were not always clear and often had to be further explained for the students' comprehension. In the future, the course could benefit from adapting a greater

relationship between the homework and quizzes as well as allowing more time for mini-lectures and practice problems. The biggest threats to the continuation of studio physics are the physical space and the small class size. The space used will always be shared with other courses, and for studio physics to be a realistic course for WPI, it would have to include many more students in each class.

6.8 Authors' Thoughts

Overall, we (the authors) deem that the course allowed greater connection between the students and instructors compared to a traditional lecture course. Over the duration of the course, the instructors were better able to determine what learning methods were working well for the class or individual students. The small class size also allowed instructors to have an opportunity to meet with individual students resulting in increased ability to help that student solve problems. Additionally, the use of many active learning strategies had a positive impact on the students. Whenever feedback was collected, there was an even distribution of students that either liked or did not like a specific activity. This told the instructors that even though there were students who did not find every activity helpful, every student found some activity helpful. This was encouraging because it means that each student was receiving instruction that worked well for them.

7. Conclusions and Future Work

If we were to run this course again, some techniques we would use again are: mini-lectures, challenge problems, clicker questions, whiteboard work, and randomized seating. Students reported that they enjoyed the mini-lectures; they were very concise and proved to be a valuable method for presenting information and keeping students' attention. Challenge problems, which occurred within the mini-lectures, helped students understand different applications of various units by combining them into one larger challenge problem while additionally improving their multistep problem solving skills. The clicker questions were also helpful for reinforcing material from the mini-lectures. Whiteboard work was very useful for encouraging collaboration and problem-solving skills amongst the student pairs. Even though the students were not fans of randomized seating, we found it encouraged peer-to-peer learning and helped make groups with balanced skill sets. In contrast, we would elect not to use the eScience Kits™ or two TA's again. Although the eScience Kits™ were easy to assemble, disassemble, and store, the instructions were unclear at times and we found it easier to create our own labs as the term progressed. Having two TA's was nice when one couldn't make it to class for whatever reason, but is ultimately unnecessary — one TA would suffice for twenty-four students. However, in the future, with an expected class size of 72 students the instructional staff should consist of a primary and adjunct professor as well as two TA's.

After reviewing student feedback, the project advisor, who was also the primary instructor, would make several changes to the course. The worksheets would be due at 8 o'clock in the morning the next day rather than the same night and the amount of

homework would be shortened from four hours to two hours per week to allow for more independent study time. At the beginning of the course, it would be emphasized that the lectures will be informal and that the students will need to be more independent learners. Additionally, five to ten minute videos about each lecture topic would be made available to students. The Mastering Physics preparatory work would come with reminders to skim the textbook and more problems from the textbook would be utilized in class for practice whiteboard problems. Instead of utilizing a six-quiz format, it would be changed to a three-test format, each test being worth 20% of the students' final grade. Approximately five conceptual multiple-choice questions would be added to the tests to support content learning. Finally, the lab instructions would be streamlined and made much more clear to the students.

The findings of this project are not generalizable beyond this studio course. The studio mechanics course is still in its infancy at WPI and will continue to be altered to better fit students' needs. The future will also come with less of a selection bias. There is the possibility that students who took the pilot studio physics course took the course not for its intended purpose of encouraging hands-on learning, but rather, because they believed that the course would be "safer" than the traditional lecture since it was the first offering of the course. Once studio physics has been firmly established at WPI, it is likely that nearly all students who register for the course will do so because they would benefit from the hands-on learning approach.

In summary, studio physics has the potential to be an effective teaching method at WPI. All students in the pilot course who responded to, "Should we continue studio classes?" encouraged the continuation of studio physics. Additionally, the WPI Physics

Department and administration have shown support. Although there are no current plans for a traditional lecture comparison group at WPI, the mechanics course will be offered again in the 2017-2018 academic year as well as a pilot electricity and magnetism course. The Foisie Innovation Studio, currently being constructed at WPI is expected to be completed in the upcoming years and will have a dedicated studio space that can hold up to 72 students. Studio physics has proven to be an effective alternative learning method and the data from this pilot course indicate that it will be a welcomed addition to the curriculum at WPI.

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Appendix A - Laboratory Reports for eScience™ Mechanics Experiments

Appendix A includes the authors' completed informal laboratory reports for the mechanics experiments in the eScience™ Kits. Lab 2 is intentionally excluded as it had little to no value to the course material. Conclusions of the laboratory reports focus more on the evaluation of the educational value of the experiment rather than explaining physical phenomena discovered.

Lab 1 - Introduction To Science
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Abstract:
The introduction to science will be a useful lab because it will establish a stable baseline of knowledge that students will need for the remainder of the course. Many of the ideas and calculations introduced in this lab are important characteristics of a credible lab report.

In this report, we complete all of the questions posed to the students in Lab 1, and discuss why this lab would be useful.

Introduction:
The purpose of this lab is to learn how to apply the scientific method by making observations, developing hypotheses, identifying variables and controls, collecting and analyzing data, and making conclusions. This lab also teaches us how to use calculations and measurement to connect percent error, significant figures, conversions, accuracy, and precision to scientific reasoning, as well as how to write and format a lab report.

Materials and Methods:
Read the introduction to science, and answer all of the questions. No materials besides the lab instructions and something to record the answers are needed.

Results:
Exercise 1: Data Interpretation

1. The information in table 4 shows that at 0 ppm oxygen, there are no fish because the fish need oxygen to survive. As the concentration of dissolved oxygen increases, so does the amount of fish in the water. A global maximum occurs at 12 ppm (15 fish).
2. Based on the table above, you can develop the hypothesis:
    If there is dissolved oxygen in a body of water, then the amount of fish that can live in the water depends on the amount of dissolved oxygen.

3. You can test this experiment by continuing to collect data of Number of Fish against the concentration of dissolved oxygen.
4. The independent variable is the amount of dissolved oxygen.
   The dependent variable is the amount of fish in the water.
5. A control in this experiment would be any body of water of known oxygen concentration and number of fish.
6. A scatterplot would be appropriate because it shows trends in the graph and can show long term increase or decrease.

Number of Fish vs. Concentration of Dissolved Oxygen
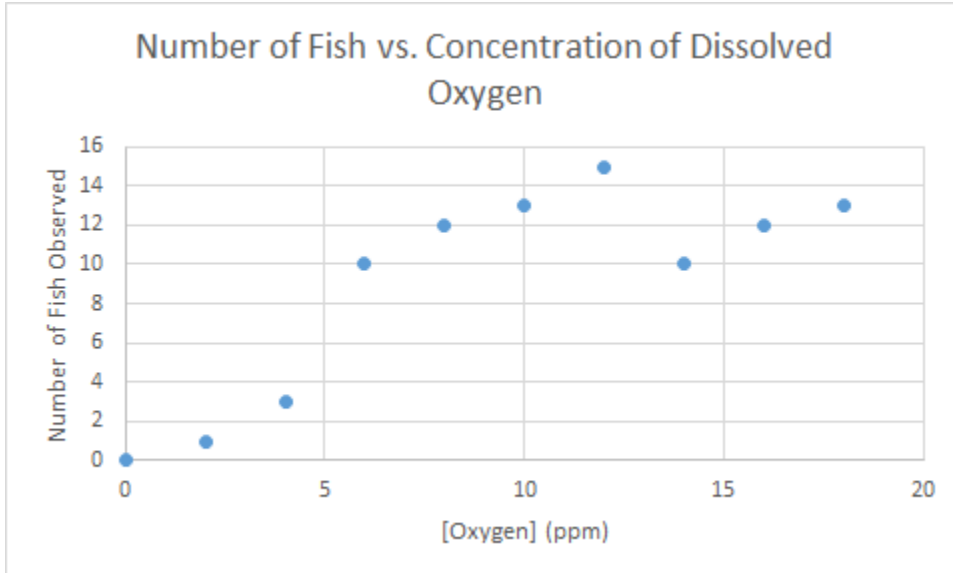
7.
8. The data in the graph shows that 12 ppm oxygen is an optimal concentration of oxygen because the most fish can survive at that concentration.

Exercise 2: Testable Observations
1. "A plant grows three inches faster per day when placed on a window sill than it does when placed on a coffee table in the middle of the living room." This observation is testable.
   a. This observation is quantitative.
   b. Hypothesis: If the plant is placed on a window sill, then it will grow at a faster rate than if it is placed on a coffee table in the middle of the living room. Null Hypothesis: If the plant is placed on a window sill, then it will grow at the same rate than if it is placed on a coffee table in the middle of the living room.
   c. I would start with two plants, placing one on the window sill and one on the coffee table to compare their growth rates.
   d. The independent variable would be the placement of the plant while the dependent variable would be the growth rate of the plant.
   e. Positive control: height of plant. Negative control: type of plant.

f. With a ruler.

g. Height vs time plot for both plants.

h. I will compare the growth rates.

2. "The teller at the bank with brown hair and brown eyes is taller than the other tellers." This observation is not testable.

3. "When Sally eats healthy foods and exercises regularly, her blood pressure is 10 points lower than when she does not exercise and eat fatty foods." This observation in testable.

   a. This observation is quantitative.

   b. Hypothesis: If Sally eats healthy food and exercises regularly, then her blood pressure will decrease. Null Hypothesis: If Sally eats healthy food and exercises regularly, then her blood pressure will remain the same than if she does not eat healthy food and exercise regularly.

   c. I would have Sally not eat healthy food and exercise regularly for a period of two weeks and record her blood pressure at the beginning, middle, and end of the two week period and compare those results to a period of two weeks where Sally did eat healthy food and exercise regularly.

   d. The independent variable would be whether or not Sally is eating healthy and exercising regularly, while the dependent variable would be her blood pressure.

   e. Positive control: Sally's blood pressure. Negative control: other aspects of Sally's routine.

   f. With a sphygmomanometer.

   g. With a bar graph.

   h. I will compare her blood pressure while eating healthy and exercising regularly with her blood pressure while not eating healthy and exercising regularly.

4. "The Italian restaurant across the street closes at 9 pm but the one two blocks away closes at 10 pm." This observation is not testable.

5. "For the past two days, the clouds have come out at 3 pm and it has started raining at 3:15 pm." This observation is not testable.

6. "George did not sleep at all the night following the start of daylight savings." This observation is not testable.

Exercise 3: Conversion

1. 46,756,790 mg * 1g/1000mg * 1kg/1000g = 4.675679 kg

2. 5.6 hrs * 60 min/hr * 60 sec/min = 20,160 sec

3. 13.5 cm * 1 in/ 2.54 cm = 5.31 in

4. 47 Degrees Celsius => (9/5)*C+32 = 166.6 Degrees Fahrenheit

Exercise 4: Accuracy and Precision

What is accuracy and precision?

        Accuracy is how close a set of values is to a known or expected value.

        Precision is how close a set of values are to one another.

        Accuracy is analogous to how close you are to the bulls-eye, while precision is analogous to your grouping.

1. During gym class, four students decided to see if they could beat the norm of 45 sit-ups in a minute. The first student did 64 sit-ups, the second did 69, the third did 65, and the fourth did 67.
   a. This information is precise but not accurate because the students all did a similar number of situps but no students were relatively close to the expected value.

2. The average score for the 5th grade math test is 89.5. Four 5th graders took the test and scored 89, 93, 91 and 87.
   a. This information is both precise and accurate because the test scores are close together and also close to the average score.

3. Yesterday the temperature was 89°F, tomorrow it's supposed to be 88°F and the next day it's supposed to be 90°F. The average temperature for September is 75°F degrees.
   a. This information is precise but not accurate, because the temperatures were all relatively similar but far from the average temperature for September.

4. Four friends played the game horseshoes. Their results are shown to the right.
   a. In the photo, all of the horseshoes are close to one another and all are close to the pin, meaning that the horseshoes are both precise and accurate.

5. A local grocery store held a contest to see who could most closely guess the number of pennies inside a large jar. The first six people guessed the numbers 735, 209, 390, 300, 1005 and 689. The jar actually contains 568 pennies.
   a. The six guesses are neither precise nor accurate because they widely vary from each other and none are very close to the actual number.

Exercise 5: Significant Digits and Scientific Notation

1. 405,000 has 3 significant digits
2. 0.0098 has 2 significant digits
3. 39.999999 has 8 significant digits
4. 13.00 has 4 significant digits
5. 80,000,089 has 8 significant digits
6. 55,430.00 has 7 significant digits
7. 0.000033 has 2 significant digits
8. 620.03080 has 8 significant digits

Part 2
1. 70,000,000,000 = 7*10^10
2. 0.000000048 = 4.8*10^-8
3. 67,890,000 = 6.789*10^7
4. 70,500 = 7.05*10^4
5. 450,900,800 = 4.509008*10^8
6. 0.009045 = 9.045*10^-3
7. 0.023 = 2.3*10^-2

Exercise 6: Percent Error
The percent error calculation is:

$$\% \, Error \; = \frac{|experimental \, -actual|}{actual}$$

1. A dad holds five coins in his hand. He tells his son that if he can guess the amount of money he is holding within 5% error, he can have the money. The son guesses that he is holding 81 cents. The dad opens his hand and displays 90 cents. Did the son guess close enough to receive the money from his father?
    a. The difference between 81 and 90 is 9, and 9 divided by 90 is 1/10 or 10 % error, therefore the son does not get the money.

2. A science teacher tells her class that their final project requires the students to measure a specific variable and determine the velocity of a car with no more than 2.5% error. Jennifer and Johnny work hard and decide the velocity of the car is 34.87 m/s. The teacher informs them that the actual velocity is 34.15 m/s. Will Jennifer and Johnny pass their final project?
    a. The difference between the experimental value and actual value is 0.72 m/s. Dividing by the actual value of 34.15 yields a 2.1% error. Jennifer and Jhonny will pass their final.

3. A locomotive train is on its way from Chicago, IL to Madison, WI. The trip is said to last 3.15 hours. When the train arrives in Madison the conductor notices it actually took them 3.26 hours. The train company prides itself on always having its trains to the station within a 3% error of the expected time. Will the train company live up to its reputation on this trip?
   a. The difference between the expected time and the actual time is 0.11 hrs. The percent error is 3.4% so the train company did not live up to it's reputation and therefore loses some street cred.

4. A coach tells his little league players that hitting a 0.275 batting average, within 7% percentage error, means that they had a really great season. Seven year old Tommy ended the season hitting a 0.258 batting average. According to his coach, did he have a great season?
   a. Tommy had a 6.2% deviation from the batting average and therefore had a great season.

Exercise 7: Experimental Variables
1. A study is being done to test the effects of habitat space on the size of fish populations. Different sized aquariums are set up with six goldfish in each one. Over a period of six months, the fish are fed the same type and amount of food. The aquariums are equally maintained and cleaned throughout the experiment. The temperature of the water is kept constant. At the end of the experiment the number of surviving fish are surveyed.
   a. The independent variable is the size of the fish habitats.
   b. The dependent variable is the size of the fish population.
   c. The food, maintainance, and temperature are all controls.

2. To determine if the type of agar affects bacterial growth, a scientist cultures E. coli on four different types of agar. Five petri dishes are set up to collect results:
   i. One with nutrient agar and E. coli
   ii. One with mannitol-salt agar and E. coli
   iii. One with MacConkey agar and E. coli
   iv. One with LB agar and E. coli
   v. One with nutrient agar but NO E. coli

   All of the petri dishes received the same volume of agar, and were the same shape and size. During the experiment, both the temperature at which the petri dishes were stored and at the air quality remained the same. After one week the amount of bacterial growth was measured.

b. The different nutrients administered to the E. Coli colonies are the independent variables.
c. The growth of the E. Coli is the dependent variable.
d. The temperature and air quality are controls, and the Nutrient agar with no E. Coli is a negative control. It is a negative control because there is no expected response from this control group.

Conclusion:

Overall, this lab will be very useful to re-establish a baseline of knowledge and techniques for students. Some of the material in this lab may seem trivial to some students but but it may also be new to others. Therefore, it is important to run this lab so that all students can be expected to know the basics in data collection, interpretation, and presentation. All student scan now be expected to understand the skeleton of a lab report, the basics of interpreting data and identifying patterns, the percent error calculation, the determination of dependent and independent variables, the use of significant figures, the difference between accuracy and precision, and scientific notation.

Lab 3 - Measurements and Uncertainty

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Abstract:

Uncertainty is an important part of taking measurements. Students need to understand that each measurement device is not perfect. Measurement devices are made to measure on certain scales, as you increase the scale, the accuracy of the measurement decreases. On a smaller scale the error of measurements decreases because the devices are more accurate. For example, most force sensors used in mechanics courses have two settings ~10 N or ~50 N. The 10 N setting will yield more accurate measurements between -10 N and 10 N, but will be unreliable outside of that range. The 50 N setting makes the sensor reliable on a scale of -50 N to 50 N, a much wider range the the 10 N setting, but uncertainty in the sensor increases to compensate for the increases range. As a general rule, uncertainty will increase with the magnitude of the measurement.

Introduction:

In this lab, students will use a Vernier scale and explain reasonings behind where error comes from while using this tool. They will also be determining the uncertainty for a ruler, caliper, spring force scale, and stopwatch. Finally, students will determine the density of the mass set.

Materials and Methods:

Marble, ruler, string, 8 oz Styrofoam cup, Vernier caliper, washer (we used a bottle cap), 5 N spring scale, 10 N spring scale, 5 lab kit or household items, stopwatch, constant drop height, mass set.

Results:

Pre-Lab Questions

1. 24 mm
2. A measuring tool will never be exact, especially in these labs.

Experiment 1: Rulers vs. Calipers

	Ruler		Caliper	
Object	Measurement (cm)	Uncertainty (cm)	Measurement (cm)	Uncertainty (cm)

Marble Diameter	1.3	0.05	1.310	0.0025
Bottle Cap (outer diameter)	3.1	0.05	3.050	0.0025
Bottle Cap (inner diameter)	2.8	0.05	2.720	0.0025
Bottle Cap Thickness	0.1	0.05	0.205	0.0025
String Length	30.7	0.05	31.5	0.0025
Styrofoam Cup Height	8.6	0.05	9.060	0.0025

1. Although the caliper was more precise than the ruler, it was not easy to use for all objects. The ruler was a better choice for the string length while the caliper was the better choice for the marble diameter. Both tools were equally as useful for the bottle cap and styrofoam cup.
2. Rulers and calipers are both relatively difficult to use with objects that are longer than the tool itself. The precision for both tools are as good as it's going to get with tools that size / tools that we can hold in our hands.
3. When using a ruler for items that are longer than the ruler, more uncertainty is present since you have to shift either the ruler or the item to measure the entire thing. For a caliper, some items are not able to easily stay inside the clamp part of the caliper.

Experiment 2: The Spring Force Scale

Object	5N Spring Scale (g)	Uncertainty (g)	10N Spring Scale (g)	Uncertainty (g)
Joe's Phone	220	5	220	10
Graphing Calculator	290	5	280	10
Sophia's Left Shoe + Joe's Right Shoe	> 500	-	580	10

| Bottle of Vegetable Oil | > 500 | - | 700 | 10 |

1. Advantages: lighter, more compact, easy to use. Disadvantages: spring can be necked with repeated use, small range of mass that it is able to measure.
2. If the mass hanging from the spring scale is not perfectly still, there can be some fluctuation in the position of the part of the scale where you measure the mass; the part of the scale you use to measure the mass is relatively thick and can lead to trouble figuring out what the mass is on the scale.

Experiment 3: The Stopwatch

Drop (Trial)	Time (s)
1	0.66
2	0.59
3	0.60
4	0.54
5	0.58

1. Advantages: more precise than just counting. Disadvantages: human error.
2. Human error.

Experiment 4: Density of the Mass Set

Quantity	Measurement	Uncertainty
Height, h (cm)	2.350	0.0025
Base Edge Length, b (cm)	1.505	0.0025
Volume, v (cm^3)	13.829	**N/A**
Mass, m (g)	100	10
Density (g/cm^3)	7.231	**N/A**

1. Zinc.

Conclusion:

In this lab, we observed the advantages and disadvantages of various tools, such as the Vernier caliper, a ruler, spring scales, and a stopwatch. We also learned about error and uncertainty. Finally, we were able to determine the density and material of the 100g mass from the mass set. This lab can help teach students about uncertainty and where some error may be coming from in future labs. Overall, we found this lab to be worthwhile and did not have any issues completing it; although it may be difficult to find '4 household items' in the lab so we may want to consider having pre-determined items to use in Experiment 2.

Lab 4 - 1D Kinematics
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Pre-Lab Questions:

1. What does a positive and negative slope represent for a velocity vs. time graph?

    The Slope of a velocity vs. Time graph represents the acceleration of the object.

2. A ball is tossed vertically into the air. What is its acceleration at its maximum height?

    The acceleration on the ball is constant and equal to g, -9.8 m/s^2

3. ?

    As they fall they will be gaining speed at the same rate (they are both under acceleration due to gravity) but as they gain speed, the distance between them will increase.

4. Derive the second kinematic equation by integration of the first kinematic equation. Derive the third kinematic equation by using algebra to combine the first and second kinematic equations.

    This question is intentionally unanswered because kinematic equations will be derived in class.

5. Predict and construct the position, velocity, and acceleration vs. time graphs for a ball tossed in the air.

Velocity

Time

Acceleration

Time

-9.8 m/s^2
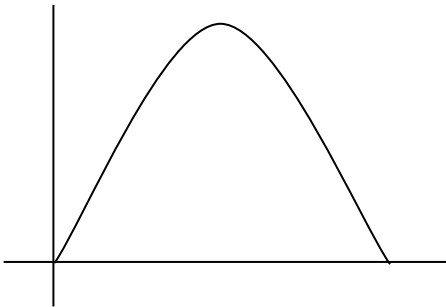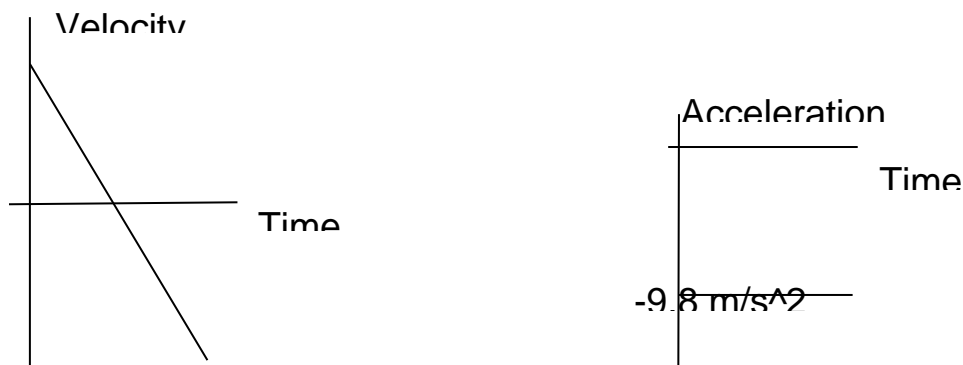
Abstract:

This lab is designed to teach students the equations that describe one dimensional translational motion. This is the starting point for two and three dimensional motion, as the equations are easily adaptable to more dimensions. The understanding and visualization of one dimensional motion is often the first part of a course where a student finds themselves doing physics and not simply mathematics.

Introduction:

In this lab students will learn the application of the one dimensional kinematic equations. Analyze One dimensional motion graphs. Predict position, velocity, and acceleration vs. time graphs, and calculate average and instantaneous velocity and acceleration.

Materials and Methods:

A catch pan	6 Hex Nuts	Scissors	Stopwatch
2.5 m string	Tape Measure	Something tall to stand on	

1. Develop a hypothesis for testing the effect of varying distances on time for objects in free fall. What do you predict will happen?

2. Use the measuring tape and scissors to measure and cut 2.5 m of string.

3. Tie the hex nuts 40 cm apart along the length of the string, starting with one on the end (Figure 6a). There may be extra string on one end of the set up.
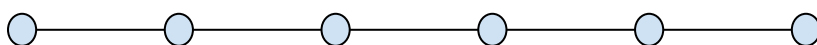
4. You will have to stand on something tall enough for the length of string to be suspended. Try a chair, a ladder, or stairs with an open railing to one side.

5. Hold the string over the pan so that the first hex nut is slightly above the metal surface. Let the hex nuts come to as much of a rest as possible before dropping them.

6. Let go of the string and observe the resulting pattern of "clangs" as each hex nut hits. Do this several times to get an idea for the pattern.

7. Keeping one hex nut on the end, change the spacing between each successive hex nut to follow the series: 9, 27, 45, 63, and 81 cm. Drop the string several times to observe the new pattern.

8. Remove one hex nut from the string.

9. Use the tape measure to choose a distance no taller than the top of your head. Mark the height with a piece of tape on a wall or stable, vertical surface. Record your drop height.

10. Use the stopwatch to record how long it takes the hex nut to hit the metal pan in Table 1. Repeat two more times, and find the average.

Results:
Auditory Observations of Equally Spaced Hex Nut Pattern:
The hex nuts sounded a pattern in which there was even spacing between each nut hitting the floor. Each ping of the hex nut hitting the ground was equally spaced.

Trial	Drop Height (m)	Time (s)
1	2.65	0.75
2	2.65	0.70
3	2.65	0.71
Average	2.65	0.72

Auditory Observation of Unequally Spaced Hex Nut Pattern:
The hex nuts were dropped so that they were farther apart as they were placed higher on the string. (ie: the 9 cm grouping was closest to the ground). The time between

pings as the nuts hit the floor elongated. It was rapid at first but took longer near the end.

Trial	Drop Height (m)	Time (s)
1	2.65	0.80
2	2.65	0.74
3	2.65	0.72
Average	2.65	0.75

Conclusion:

In this experiment we observed qualitatively the pattern sounded when hex nuts hit the ground in two different orientations. We also measured the time it took the last nut (which was dropped from the same height throughout the experiment) to hit the ground, to show that the spacing of the nuts doesn't matter, they still fall at the same speed. Overall I am not certain that this was the best experimental protocol for one dimensional motion. An addition to the experimental protocol could be to have students, given acceleration due to gravity, construct position, velocity, and acceleration vs. time graphs for the hex nut farthest from the ground.

Lab 5 - 2D Kinematics and Projectile Motion

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Pre-Lab Questions:
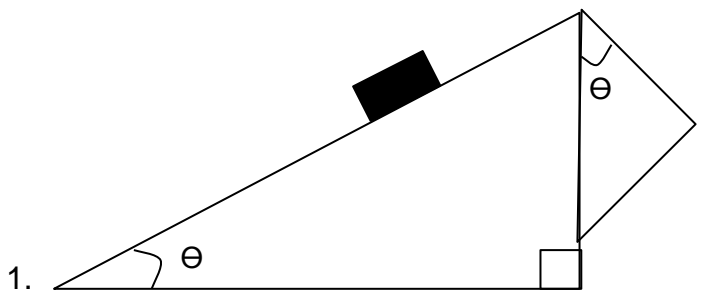
1.

$v_f^2 - v_i^2 = 2ad = 2g\sin(\Theta)d$

$v_f = \sqrt{[2g\sin(\Theta)d]}$

2. $d = v_it + (\frac{1}{2})at^2$

$t^2 = (2d)/(a)$

$t = \sqrt{(2d/a)}$

3. x: $d = v_{0x}t \rightarrow t = d/v_{0x}$

y: $h = (\frac{1}{2})gt^2 \rightarrow t = \sqrt{(2h/g)}$

$\sqrt{(2h/g)} = d/v_{0x}$

$d = v_{0x}\sqrt{(2h/g)}$

4. For an object launched from the ground at an angle θ from the horizontal with initial velocity V, the kinematic equations are as follows:
X: $R=V\cos(\theta)t$
Y: $0=V\sin(\theta)t-0.5gt^2$ or $gt=2V\sin(\theta)$
Solve each equation for t and set equal to each other:
$(R)/(V\cos(\theta))=(2V\sin(\theta))/g$ isolating R and applying the double angle sine identity
$R=V^2\sin(2\theta)/g$
By this equation, the range will increase with the launch velocity, and for any given velocity the range will be at a maximum at an angle of 45 degrees.
5. To Prove that the range is at a maximum at 45 degrees take the derivative of the range equation with respect to the angle θ
$dR/d\theta = 2V^2\cos(2\theta)/g$

Evaluating for θ between 0 and 90 degrees, R is increasing on the interval θ = 0 to 45, reaches a maximum at θ = 45 and is decreasing on the interval θ = 45 to 90.

Abstract:
Two Dimensional Motion is the next step in understanding how objects can move in space. Utilizing Two dimensional motion allows an object to move in more than a straight line, the object can now move anywhere in a plane. The motion of objects in a plane has much more application than that in a straight line, most nominally, projectile motion (the motion of an object with acceleration acting in one direction but not necessarily the same direction that the object is travelling).

Introduction:
In this lab students will conduct two procedures to explore 2-D Motion. The Ramp lab will have students utilize the idea of breaking gravity into a component down a ramp, and the idea that an object in free fall will reach the ground at the same time despite having different horizontal velocities. In the rocket lab, students will be challenged by using a change in rocket launch angle as a tool to calculate the range of the rocket.

Materials and Methods:
Experiment One

You will need:

The Sheet of Carbon Paper	Fishing Line	Sheet of Printer
Tape Measure	A fishing sinker	Pencil
Masking Tape	Table	A Marble
Protractor	The ramp included	

Ramp Set Up
1. Separate the two pieces; one long and narrow piece to provide the ramp, and one wider piece to provide the base.
2. Fold the wider section along the perforations to form a triangular stand.
3. Insert the tab through the slot to construct a triangular stand (Figure 4, Part 2).
4. Insert the tab on long, narrow piece into one of three slots on the triangular stand. Different slots correspond to different inclines.

Procedure

1. Find a table upon which to perform the experiment. Place the ramp so that its bottom edge is positioned at the edge of the table. You will be rolling marbles down the ramp and off the table in this experiment.

2. Use a protractor to measure the incline. Record the angle of the incline in Table 1.

3. Use a pencil to mark three different locations on the ramp at which you will release the marble. This will ensure the marble achieves the same velocity with each trial.
Hint: Use locations near the top, middle and bottom of the ramp.

4. Create a plumb line by attaching the fishing sinker to the fishing line.

5. Hold the string to the edge of the table, and use a piece of masking tape to mark the spot at which the
weight touches the ground.
Note: The length of the plumb line will help you measure the exact distance from the edge of the ramp to the position where the marble lands.

6. Begin the experiment by releasing the marble from the first position you marked on the ramp in Step 3. In
other words, release the marble from the highest position which you marked on the ramp.

7. Carefully observe where the marble hits the ground and place a piece of white printer paper at that location.
Secure the paper to the ground with a small piece of masking tape. Make sure the paper can moved
when the different ramp positions are tested. Try to center the printer paper over the spot where the marble
hit the floor.

Figure 4: Ramp set-up diagram.

8. Set the carbon paper on the printer paper so that the light side faces up. When the marble hits the carbon
paper, it will leave a mark on the printer paper.

9. Place the marble at the same drop mark you just tested and release it.

10. Use the tape measure to measure the distance the marble traveled. Do this by measuring the distance
between the masking tape mark where the fishing sinker met the floor and the carbon mark on the printer
paper. Record the distance in Table 1.

11. Once you have recorded the distance in Table 1, put an "X" over the mark you just measured so you do
not reuse it.

12. Repeat Steps 9 - 10 three more times and record your data in Table 1.

13. Repeat Steps 6 - 12 for the remaining two ramp distances you marked in Step 2. Record you results for

the second ramp distance in Table 2, and the third ramp distance in Table 3.

Results:

Experiment 1: Distance Travelled by a Projectile

Table 1: Range and Velocity of Projectile at Ramp Distance 1
Ramp Incline (degrees): 15
Ramp Distance (m): 0.329

Trial	Measured Distance (m)
1	0.431
2	0.441
3	0.436
4	0.429
Average	0.434

Table 2: Range and Velocity of Projectile at Ramp Distance 2
Ramp Distance (m): 0.205

Trial	Measured Distance (m)
1	0.326
2	0.334
3	0.329
4	0.333
Average	0.331

Table 3: Range and Velocity of Projectile at Ramp Distance 3
Ramp Distance (m): 0.076

Trial	Measured Distance (m)
1	0.184
2	0.187
3	0.188

4	0.186
Average	0.186

Post-Lab Questions:

1. *Table 4: Velocity and Range Data for all Ramp Distances*
   h = 0.915m

Ramp Distance (m)	Calculated Velocity (m/s)	Predicted Range (m)	Average Actual Range (m)	Percent Error (%)
0.329	1.29	0.558	0.434	22.22
0.205	1.02	0.441	0.331	24.94
0.076	0.621	0.268	0.186	30.60

2. Our predicted ranges tended to be at least 0.1m greater than our experimental ranges. This is most likely due to air resistance and human error by not being able to use a consistent amount of pressure each time the rocket is launched.
3. The two pellets will hit at the same time due to gravity being constant. We've discussed this so many times.
4. In the pre-lab questions, we determined that $d = v\sqrt{(2h/g)}$. Therefore, doubling the initial velocity would double the distance travelled by the marble.
5. The acceleration is constant. #gravity

Experiment 2: Squeeze Rocket Projectiles

You will need:
Masking Tape   Stopwatch   Mirror Support
Tape Measure   Printer Paper   Pencil
Protractor   Squeeze Rockets and Bulb

Procedure:
1. Place the unused side of the printer paper face up on a flat work space and secure with a piece of masking tape.
2. Use a pencil to mark the spot in the middle of the printer paper. This is the where the rockets will be launched every trial.
3. Stabilize a protractor so that it stands up vertically by inserting the flat part of the protractor into the mirror support. Using a protractor, align the rocket to a 90° angle. In other words, it should be vertically directed upward.

4. Load a Squeeze Rocket™ onto the bulb.

Note: The Squeeze Rocket™ is a trademarked product name. The "rocket" itself does not use a self-propelled mechanism. After the Squeeze Rocket™ is launched, gravity is the only major force which acts upon the "rocket".

5. Predict how far you believe the rocket will be propelled from its original position if you squeeze the bulb.

Record your prediction in Table 5.

6. Squeeze the bulb (you will need to replicate the same pressure for each trial), and simultaneously start the stopwatch upon launch. Measure and record the total time the rocket is in the air. Repeat this step three times, and average your results. Record all data in Table 5.

Note: You may wish to include a partner for this step to work the stopwatch.

7. Calculate the launch velocity of the rocket using the kinematics equations. Record your calculation in Table 5.

Hint: You can take the initial height as zero. The vertical velocity is zero at the peak of the flight, when the time is equal to t/2.

8. Choose three new angles from which to launch the rocket. Record the angles you select in Table 5.

9. Before launching the rocket, use the following equation to calculate the expected range using the launch velocity and the angle from which the rockets will be fired. Remember that you can use zero for any initial positions, and that the acceleration due to gravity, g, is -9.8 m/s2. Record the expected ranges in the Predicted Range column in Table 5.

10. Next, align the rocket with the first angle choice and fire it with the same force you used initially. Squeeze the bulb and measure the distance traveled with the tape measure. Record the distance propelled for four, separate trials at this angle. Then, average the four trials and record in Table 5.

Note: Try to record launches where the rocket travels in a parabola and does not stall or flutter at the top.

11. Repeat Step 9 - 10 for your remaining angles. Record all data in Table 5.

12. Record the percent error between your calculated and actual values in the last column.

Use your results to draw a conclusion about the angle that provides the greatest range and the least range.

R = v2 sin(2θ)/g

Calculate Launch Velocity by utilizing the 90 degree trials. Take the average time as your time interval. Using the kinematic equation $y=y_o+V_yt+0.5a_yt^2$ where y and y_o are both zero V_y is the unknown, and a_y is -g.

Table 5: Projectile Data for Rockets with Different Launch Angles

Launch Velocity (m/s)	Initial Angle	Time (s)	Average Time (s)	Predicted Range (m)	Actual Range (m)	Average Range (m)	Range Percent Error (%)
6.419	**90°**	1.34		0	1.670		
	90°	1.23		0	1.216		
	90°	1.28		0	0.225		
	90°	1.39	1.31	0	1.268	1.094	N/A (divide by 0)
	Student Selects: 20°	0.66		2.70	2.775		
	Student Selects: 20°	0.52		2.70	2.834		
	Student Selects: 20°	0.53		2.70	2.818		
	Student Selects: 20°	0.51	0.555	2.70	3.401	2.957	9.51
	Student Selects: 45°	1.14		4.20	2.930		
	Student Selects: 45°	0.97		4.20	3.352		
	Student	1.00		4.20	3.507		

	Selects: 45°					
	Student Selects: 45°	0.84	0.9875	4.20	3.194	3.246	22.71
	Student Selects: 70°	1.51		2.70	1.117		
	Student Selects: 70°	1.41		2.70	1.912		
	Student Selects: 70°	1.57		2.70	1.775		
	Student Selects: 70°	1.35	1.46	2.70	1.164	1.492	44.74

Post Lab Questions

1. Use your results to draw a conclusion about the angle that provides the greatest range and the least range.

   Based on the range equation and its derivative with respect to θ, the range reaches a maximum when θ is equal to 45 degrees (when air resistance is included it is actually slightly less than that). This is supported by the experimental data.

2. Comparing the experimental value for greatest range to the expected value

   Obs.= 3.246 m   Exp.= 4.20 m   % Error = 22.7%

   What Error could have caused this.

   This error was most likely generated by air resistance, the rockets were awfully flimsy and likely were buffeted by any air current in the room. There may also be error in the fins on the rockets. The experiment depends on the rocket fins staying straight, so the rockets don't deviate from the desired path. However, the fins were very

malleable and had to be adjusted frequently.

3. The best way to redesign the experiment would be to utilize a more reliable and consistent method for launching the rocket and the rocket's flight.

4. How could kickers on a football team apply their knowledge of projectile motion to improve their game?
    List at least two other examples in sports where this concept would apply.

    Kickers on a football team could kick the ball farthest by kicking the ball at a 45 degree angle. Usually this is not optimal because they have to kick the ball over the heads of defenders trying to block the kick. To compensate, the kicker kicks the ball higher, reducing range of the kick to ensure that the kick is not blocked.
    In soccer, a player could kick the ball farthest by kicking at a 45 degree angle from the turf.
    In Baseball, an outfielder could reach the farthest by throwing the ball at a 45. However, they could reach the base faster by throwing the ball at a lower angle with greater velocity to a cutoff man who would do the same to the base. It is faster to throw the ball multiple times at a lower angle than it is to throw the ball once with a large angle.

Conclusion:
Overall, the educational value of this lab is worth running, however, the experimental procedure was far too time concerning. Either a different lab should be considered, or, this lab as it stands could be broken up amongst lab groups. ie in the rocket portion, have each group do a different angle, then have the class collaborate data. This lab would be very helpful to students because the problems involved with the rockets make the students utilize many different ideas within 2D-Motion (such as breaking velocity into components).

Lab 6 - Newton's Laws
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Pre-Lab Questions:

M_1

M_2

1. Draw a free body diagram for M_1

Tension

M_1g
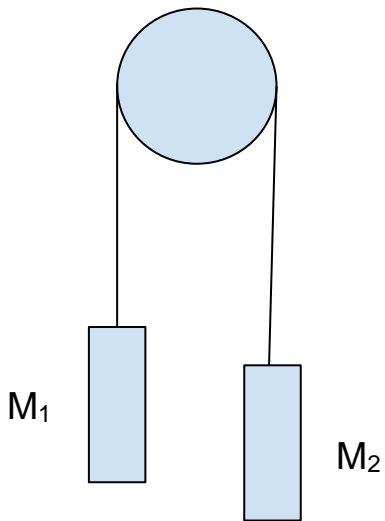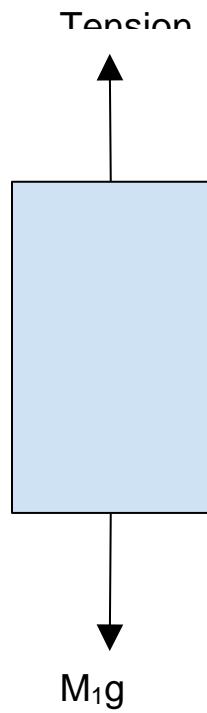
2. Draw a free body diagram for M2.

Tension

M_2g
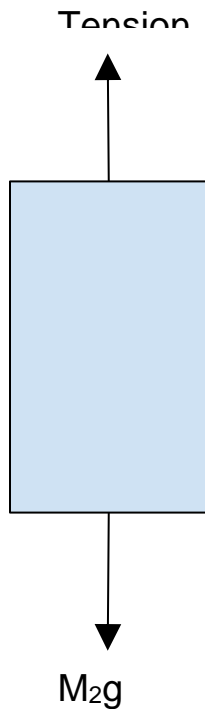
3. Apply Newton's Second Law to write the equations for M1 and M2. The result should be two equations with tension in the string, weight for each mass and accelerations for each mass (a1 and a2).
$M_1a_1=\text{Tension}(T)-M_1g$
$M_2a_2=T-M_2g$

4. The third equation is the constraint due to the string and the masses being attached.
Since the masses are connected, if the tension in the string is constant (it remains taught), the velocity and accelerations of the masses will be equal $a_1=a_2=a$.

Abstract:
Newton's Laws of motion describe fundamental concepts in physics. The first law states that any body at rest or in uniform motion will remain at rest or in uniform motion until it is acted upon by an external force. The second law states that the acceleration of an object is a function of its own mass and the net force on it. The object will accelerate proportionally to force and inversely with mass. $\Sigma F=ma$. The third law states that for every force there is an equal and opposite force. For example, if you are in

space and you push against your space ship, a force equal and opposite to the force you imparted on your ship will be imparted on you.

Introduction:
This law is designed to to teach the first and third of Newton's Laws. Students will explore inertia utilizing water and a washer falling into a cup. They will study the third law with a simple atwood's machine.

Materials and Methods:
3x5 inch notecard, 8oz Styrofoam cup, 15 washers, deep container, water, 5N spring scale, 10N spring scale, string, 0.5kg mass, pulley, masking tape, stopwatch, 2 paperclips, and tape measure.

Experiment 1 Newton's First Law
    Part 1
1. Fill a container about half full with water.
2. Perform the following patterns:
    a. Start with the water at rest and quickly accelerate it up and down.
    b. Walk with constant speed.
    c. Turn Abruptly
    d. Stop Abruptly
3. Record Observations

    Part 2
1. Place a notecard on top of a styrofoam cup.
2. Place a washer on top of the notecard above the center of the cup.
3. Hold the styrofoam cup in one and and flick the notecard out from under the washer with the other. Record Observations.
4. Repeat steps 1-3 for a total of five trials.

Experiment 2 Third Law and Force Pairs
    Part 1
1. Make sure the spring scales are calibrated using the standard masses.
2. Hook the handle of the 5N spring scale to the hook of the 10N spring scale.
3. Holding the 10N spring scale stationary, pull the hook of the 5N spring scale until the force reads 5N on it. Record the force on the 10N spring scale in Table 3.
4. Repeat Steps 2 and 3 with the 10N spring scale hanging from the 5N spring scale. Record the force on the 5N spring scale in Table 3.

Part 2
1. Suspend the 0.5kg mass in the air using the 10N spring scale. Record the force on the 10N spring scale in Table 4.
2. Tie one end of one of the pieces of string to the 0.5kg mass and the other end to the hook of the 10N spring scale.
3. Suspend the mass in the air by lifting the 10N spring scale. Record the force of the 10N spring scale in Table 4.
4. Untie the end of the string attached to the 0.5kg mass and tie it to the hook of the 5N spring scale.
5. Hook the 0.5kg mass to the handle of the 5N spring scale. Suspend the mass, scales, and string by holding the handle of the 10N spring scale. Record the values of the spring scales in Table 4.
6. Secure the pulley on a table top by tying string to one of the hooks. Then, use masking tape to secure the string to a table top so that the hook on the top of the pulley lays flat on the side of the table top (Figure 6).
7. Using the mass setup from Step 5, place the string over the pulley by unhooking one of the spring scales, feeding the string through the pulley and reattaching the string to the hook of the spring scale (Figure 6).
8. Hold the 10N spring scale in place so that the scales and mass are stationary. Record the values for both spring scales in Table 4.

Experiment 3 Newton's Second Law and the Atwood Machine
Part 1
1. Support the pulley so that objects hanging from it can descend to the floor. Do this by tying a short piece of string to one of the pulley hooks. Use a piece of masking tape to secure the string to a table top or door frame so that the pulley hangs plumb (Figure 7).
   Note: A higher pulley support will produce longer time intervals which are easier to measure.
2. Thread a piece string through the pulley so that you can attach washers to both ends of the string. The string should be long enough for one set of washers to touch the ground with the other set near the pulley. (You may attach the washers using a paperclip or by typing them on).
3. Use the spring scale to weigh the set of 15 washers. Divide the total mass by 15 to find the average mass of a washer. Record the total mass of the washers and average mass of one washer in Table 5.
4. Attach seven washers to each end of the string.
5. Observe how the washers on one side behave when you pull on the washers on the other side. Answer Post-Lab Question 1 based on your observations.

6. Add the remaining washer to one end of the string so one side of the string has seven washers (M1), and the other has eight washers attached to it (M2).
7. Determine the approximate mass of M1 and M2. Record their masses in Table 6.
8. Place M1 on the floor. Use the tape measure to measure the height that M2 is suspended while M1 is on the floor. Measure the distance M2 will fall to the floor when you release the lighter set of washers. Record the distance in Table 6.
9. Time how long it takes for M2 to reach the floor. Repeat Steps 7-8 four more times (five times total), recording the values in Table 6. Calculate and record the average time in Table 6.
10. Calculate the acceleration (assuming it is constant) from the average time and the distance the washers moved.

Part 2
1. Transfer one washer, so that there are six on one end of the string (M1) and nine on the other (M2).
2. Determine the approximate mass on each end of the string. Record the mass values in Table 7.
3. Repeat Steps 7-9 of Procedure 1. Record data in Table 7.

Results:
Experiment 1: Newton's First Law of Motion

Table 1: Motion of Water Observations

Motion	Observations
a	Water rides against sides opposite direction of acceleration
b	No change
c	Right: rides up against left side Left: rides up against right side
d	Water rides against wall in the direction of which you are walking

Table 2: Observations After Flicking Notecard Off of Cup

Trial	Observations
1	Washer fell into cup

2	Washer fell into cup
3	Washer fell into cup
4	Washer fell into cup
5	Washer fell into cup. Shocking

Post Lab Questions for Exp. 1

1. The observations of the water and the washer demonstrate Newton's First law because in all instances the water or washer resisted change in its own motion. The water rode up on the wall as resistance to changing velocity (accelerating) and the washer resisted change in motion by not moving as the notecard was moved from underneath it. The frictional forces between the card and the washer did not overcome the washer's inertia.

2. The Diagram describes the water

Direction of motion

Stopping
Force

Cup with
water in it
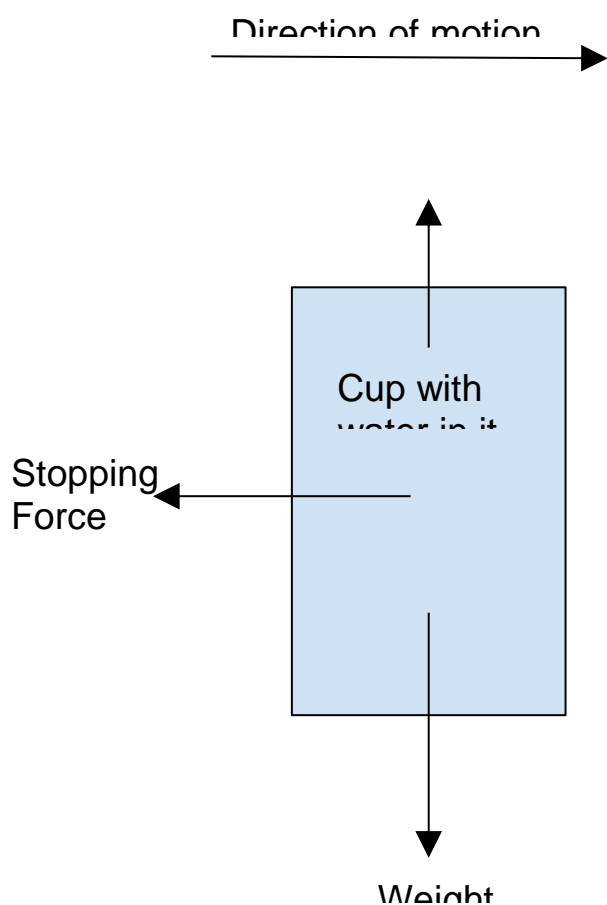
Weight

The weight of the water and the normal force are equal and opposite forces. The stopping force acting on the water causes it to accelerate towards you when you stop moving. To stop the water moving you must exert a force opposite its

direction of motion to accelerate it in the direction opposite its own motion.

3. Two instances where you feel forces in a car are accelerating and braking (ignore the fictitious Centrifugal force [turning] for now). When you accelerate, you are pressed into the seat because your body resists accelerating forward and so a force is exerted on you by the seat. When you brake, you feel as if you are being pushed forward. This is because you are in uniform motion and want to continue in uniform motion but the car is accelerating opposite your direction of motion and slowing you down.

Experiment 2: Newton's Third Law and Force Pairs

Table 3: Force on Stationary Springs

Force on Stationary 10N Spring Scale (N)
5.0
Force on Stationary 5N Spring Scale (N)
5.0

Table 4: Spring Scale Force Data

Suspension Set Up	Force (N) on 10N Spring Scale	Force (N) on 5N Spring Scale
0.5kg mass on 10N	5.0	-
0.5kg mass with String on 10N Spring Scale	5.0	-
0.5kg mass, string, and 5N Spring Scale on 10N Spring Scale	5.0	5.6
0.5kg mass, string, and 5N Spring Scale on 10N Spring Scale on Pulley	5.4	> 5.0

Post Lab Questions

1. The forces on the two spring scales were nearly equal, however, the force reading on the top scale included the weight of the spring scale below it.

2. As in Question 1, the forces on the two spring scales were nearly equal, however, the force reading on the top scale included the weight of the spring scale below.

3. This follows Newton's Third law because if I pull with a certain force down on the bottom spring, then that spring will in turn pull on the spring scale above it to equalize the force of me pulling down.

4. There was no difference in readings when the mass was directly attached to the scale vs. when the mass was attached via the string. Given that the string has negligible mass, the same mass was pulling down on the scale in both instances.

5. Based on parts 5 and 6 of the experiment, you can conclude that a string of negligible mass will have equal tension on each end of the string.

Experiment 3: Newton's Second Law and the Atwood Machine

Table 5: Motion Data

Mass of 15 Washers	0.5 N	Average Mass of	0.033 N

Table 6: Procedure 1 Motion Data

Mass of M_1 (7 washers):	0.231 N
Mass of M_2 (8 washers):	0.264 N
Height (m):	0.415
Trial	Time (s)
1	1.44
2	1.40
3	1.35
4	1.39
5	1.44

Average	1.404
Average Acceleration (m/s²)	0.421

Table 7: Procedure 2 Motion Data

Mass of M_1 (6 washers):	0.198 N
Mass of M_2 (9 washers):	0.297 N
Height (m):	0.410
Trial	**Time (s)**
1	0.84
2	0.78
3	0.81
4	0.71
5	0.73
Average	0.774
Average Acceleration (m/s²)	1.369

Post Lab Questions
1. What do you observe when there is an equal number of washers on each end of the string.

   The forces on each set of washers are equal and opposite. This means that the washers will not accelerate of their own accord, and will only be slowed down by slight frictional loses. If you give the washers a slight push, they will stay in motion for a long period of time.

2. For any set of washers on the strings.

F_T

F_T

M_1

M_2

$F_{g1}=M_1$

$F_{g2}=M_2$
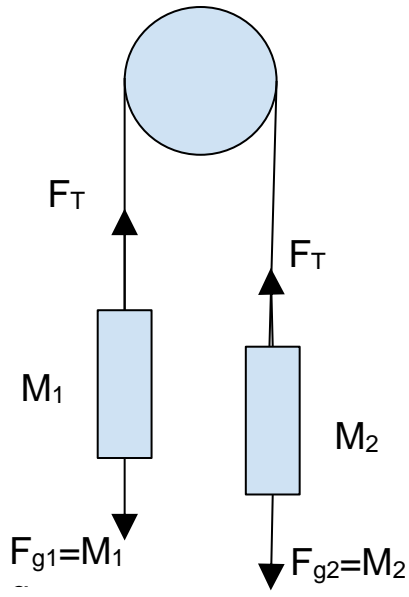
3. Using Newton's second law
   $M_1a=F_T-M_1g$ and $-M_2a=F_T-M_2g$
   The two objects are tied together so they will experience the same acceleration but in opposite directions.

4. Solving for Tension and setting the equations equal
   $M_1a+M_1g=M_2a+M_2g$
   $a=(M_2-M_1)g/(M_1+M_2)$

5. To calculate the acceleration of the washer utilize the first kinematic equation and simplify to $h=0.5at^2$

   Procedure 1 (7 and 8 washers) : experimental value = a = 0.421 m/s^2
   Theoretically $a=(M_2-M_1)g/(M_1+M_2) = (M_W)g/(15M_W)$ = or $g/15$ = 0.653 m/s^2
   Procedure 2: (6 and 9 washers) : experimental value = a = 1.369 m/s^2
   Theoretically $a=(M_2-M_1)g/(M_1+M_2) = (3M_W)g/(15M_W)$ = or $g/5$ = 1.96 m/s^2

   The percent error is as follows
   Procedure 1: 35.5%   Procedure 2: 30.2%

6. Solving each equation for a to find force of tension yields
   $(F_T-M_1g)/M_1 = (F_T-M_2g)/-M_2$
   $-M_2F_T+M_2M_1g = M_1F_T-M_1M_2g$
   $F_T = 2M_2M_1g/(M_1+M_2)$ or $2\mho g$ where is $\mho$ reduced mass

As the masses increase in difference, the value of reduced mass will approach the smaller mass. The force of tension will be approximately the weight of the lesser of the two masses.

Conclusion:

Overall, this lab was valuable yet could potentially be time consuming when it comes to adding washers to the pulley systems. We also ran into a minor inconvenience with the masking tape not being able to support the weight of the pulley system. Additionally, it may be difficult to use water in the Olin lab rooms due to the amount of electronic devices, the proximity to a water source, and the cleanup aspect of any spilled water.

Lab 7 - Circular Motion

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Abstract:
Circular motion is often a student's first experience working with rotating objects or rotation. Circular motion is an important part of physics, it introduces new sets of problems but also explains phenomena such as orbits and rotation.

Introduction:
In this experiment students will investigate some of the fundamental relationships between centripetal and tangential values. The techniques learned in this lab will be an important building stone for further study of circular motion.

Materials and Methods:
Aluminum tube, 1m fishing line, permanent marker, stopwatch, tape measure, 5 washers.

First, we ran fishing line through the aluminum pole and tied washers to each end of the fishing line (one on one end, four on the other). We then used the tape measure and permanent marker to measure and mark the fishing line with various radii measurements (0.25m, 0.40m, and 0.15m). The next step was to calculate the period for each radius. Using the marks we made on the fishing line, we spun the weights around the aluminum pole until our marks were visible and then used the stopwatch to time the period it took for the end of the fishing line with one washer to make 15 rotations.

Pre-Lab Questions:
1. Draw a free body diagram and solve for the centripetal acceleration in terms of θ and g for one person riding on the amusement park ride in Figure 3.

Tension

mg

Tension *Sin(Theta) = mg
Tension*Cosine(Theta) = ma
Divide the equations
Tangent(Theta)=g/a therefore a = g/tan(theta)
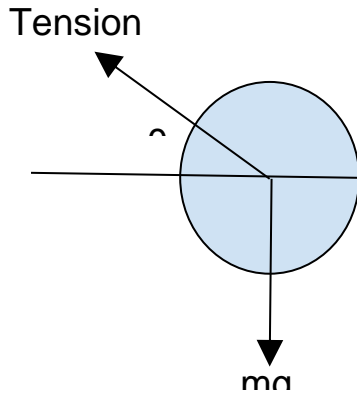
2. The Tension in the wire is equal to the weight of mass 2.
    $M_2g=M_1a_{centripetal}$

3. At the top of the circle there need not be any tension in the wire, gravity and radial acceleration will fall in the same direction. However at the bottom of the circle the tension must be twice the magnitude of gravity to maintain circular motion. This way the force of tension is a function of the angle and the radial acceleration is equal to g.

4. Initially the wheels radial velocity is $\omega=v_t/r=$ 2/2.6 = 0.769 rad/s

    The wheel comes to a stop after passing through 3π radians
    Using the equation $\omega_f^2=\omega_o^2+2\alpha\theta$ (Where final omega = 0)
    $\alpha = (-\omega_o^2)/(2\theta) =$ -0.0314 rad / s^2

Results:
Table 1: Period During Uniform Circular Motion at Varying Radii

Radius (m)	Time per 15 Revolutions (s)	Period (s)	Expected Value	Percent Error (%)
0.25	7.60	0.5067	0.501	1.14

0.40	8.88	0.592	0.635	6.77
0.15	5.15	0.343	0.389	11.8

Post-Lab Questions:

1. Mass, Gravity, Angular Velocity, Radius

2. There was error generated from two major sources.
   The timing was not exact but pretty good for 15 rotations.
   Also it was difficult to maintain the exact radius desired for a long period of time.

3. As radius increases, the period increases.

4.
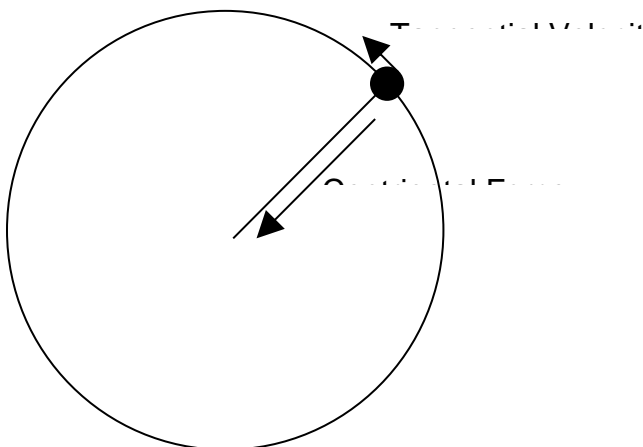
5. The equation for average tangential velocity is as follows
   V = sqrt(R*a) and in this experiment a = 4g because there was four times as much mass hanging as on the wire spinning.
   For each radius
   R = 0.25 m V = 3.13 m/s   R = 0.40 m V = 3.96 m/s   R = 0.15 m V = 2.42 m/s

6. The chairs begin to rise vertically because the vertical component of the radial tension is greater than the force of gravity on the chair.

7. If the chairs angular velocity is doubled, the tangential speed of the chairs will increase but by an unknown factor because the initial radius or the length of the string or some other length measurement is needed to to solve the problem.

Conclusion:

Overall, we found this lab to be worthwhile and not very time consuming, a contrast to the previous labs. The only drawback to this lab was when Joe had to spin the mass for the 40cm radii section since Sophia's arms were not long enough. This lab definitely has a lot of educational value for the demonstration and explanation of centripetal force and angular velocity. We did not obtain large values for percent error, showing that this lab will likely not have many problems associated with it.

Lab 8 - Gravity

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Sophia Leitzman, smleitzman@wpi.edu

Abstract:

Gravity is a fundamental force of nature. Acceleration due to gravity is an important application of rotational motion. It is also the first example of a force that changes with distance. On the surface of Earth we make the assumption that gravity is always 9.8 m/s^2 because the radius of the earth is much more significant than the height of the ground. However, when you get to an astronomical scale the distance between bodies is significant when calculating gravitational force. The gravitational force and its implications to planetary motion have helped us to understand much of the universe around us.

Introduction:

In this lab students will investigate the force due to gravity, which is known to be a constant <u>acceleration</u>. The purpose of this lab is to attain a greater understanding of the gravitational force and how the mass of objects affects the force of gravity between them. Students will study multiple objects falling to the ground and will also analyze data from Halley's Comet.

Materials and Methods:

Coffee Filter   Cork   Marble   Stopwatch
Tape Measure   Wooden Block

Experiment 1
Drop the coffee filter 10 times from a set height and record the time it take for each drop
Calculate the average time of freefall and the acceleration of freefall
Repeat for the cork, marble, and wooden block.

Experiment 2
Cut a hole for the flashlight into the bottom of the styrofoam cup and place the cup over the flashlight.
Hold the light a number of set distances from the wall and measure the diameter of the lit area.

Experiment 3
Analyze Halley's Comet

Pre-Lab Questions:

1. $ma = F = (GMm)/(r^2)$
   $a = (GM)/(r^2)$
   $a = ((6.67 \times 10^{-11})(5.97 \times 10^{24})) / ((6.371 \times 10^6)^2)$
   $a = 9.8 \text{ m/s}^2$

2. Assuming that the moon orbits the earth in a circle has a period of 27.32 days, and a radius of 380 Mm. The distance that the moon travels in one orbit is the circumference of the circle. $C = 2*pi*r = 2.39$ Gm. This distance over 27.32 days gives a tangential velocity of about 1,012 m/s. Radial acceleration is $a_r = (V_t)^2/R = 0.00269 \text{ m/s}^2$

3. $ma = F = (GMm)/(r^2)$
   $a = (GM)/(r^2)$
   $a = ((6.67 \times 10^{-11})(5.97 \times 10^{24})) / ((3.8 \times 10^8)^2)$
   $a = 0.0028 \text{ m/s}^2$

4. $x = rcos(\Theta)$
   $y = rsin(\Theta)$

Results:

Table 1: Average Free Fall Time for Various Objects

Drop Height (m)	Object	Average Free Fall Time (s)	Calculated Acceleration (m/s²)
0.92	Coffee Filter	1.175	1.33
0.92	Cork	0.434	9.77
0.92	Marble	0.434	9.77
0.92	Wooden Block	0.401	11.44

1. The rate of acceleration for the objects we used is, somehow, exactly the same for the cork and the marble, with the coffee filter having the lowest acceleration and the wooden block having the highest acceleration. The reason for coffee filter has the lowest acceleration is due to air resistance.

2. Coffee Filter: 86.43%
   Cork: 0.306%

Marble: 0.306%
Wooden Block: 16.73%

3. You would have to use the formula used in Pre-Lab Questions 1 and 3; $a = (GM)/(r^2)$.

4. Air resistance makes falling objects seem like they have different accelerations as they fall to the earth, since the air slows them down.

5. Yes; looking at Newton's Law $F = ma$, it is shown that as m increases, so does F. Additionally, if you are holding a mug in one hand and a feather in the other, the mug will feel heavier since there is more force acting on it.

6. More massive objects need more force to be able to attract it to the surface. This can also be seen using these formulas: $ma = F = (GMm)/(r^2) \rightarrow a = (GM)/(r^2)$

Table 2: Distance vs. Light Data

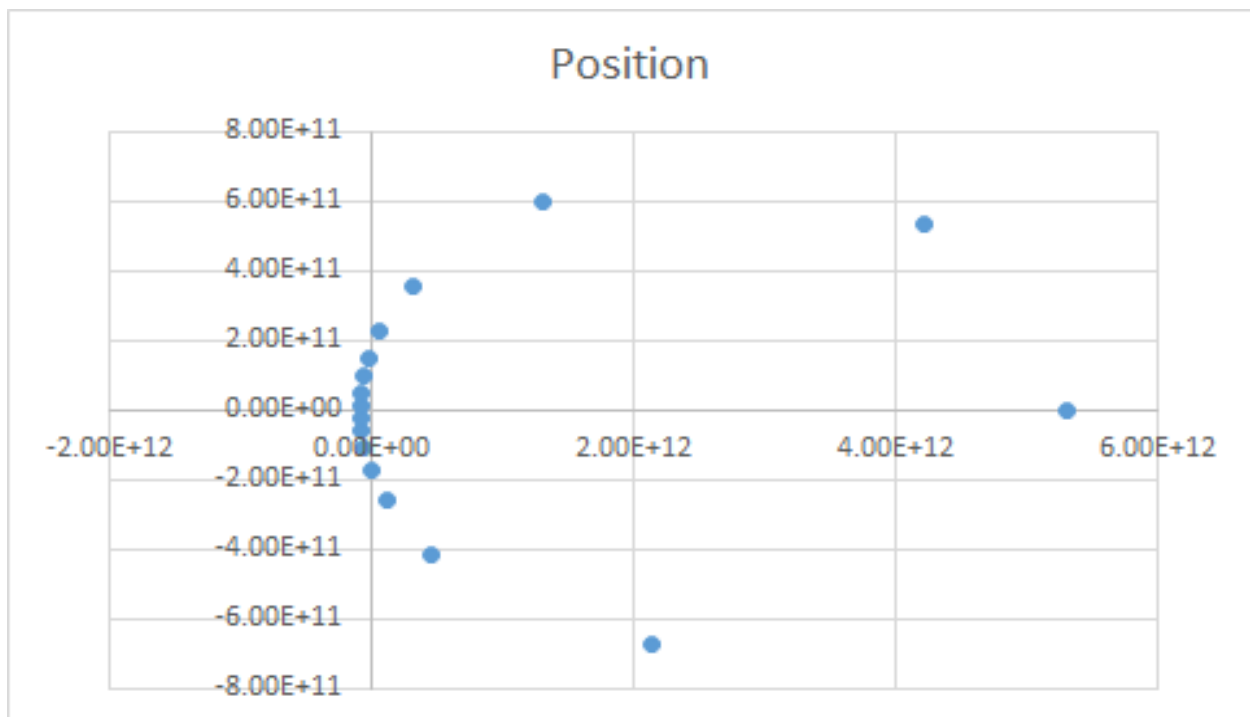| Distance From Wall (cm)	Intensity (on a scale of 1-10)	Diameter of Light (cm)	Area (cm²)
5	10	14.5	165.13
10	9	22.5	397.61
15	8	31.5	779.31
20	7	39.5	1225.42
25	6	48.0	1809.56
30	5	57.5	2596.72

1. In most instances the light area increased by a factor the square of the factor that the distance changed by. (ie if the distance doubled the area quadrupled).

2. The intensity didn't change much at the closer distances, it took a much larger distance for the intensity to change greatly.

...

*Table 3: Location of Halley's Comet During a 75 Year Period*

Ɵ (°)	r (m)	x-coordinate (m)	y-coordinate (m)	Acceleration (m/s²)	Force (N)
0	5.23 x 10^+12	5.32 x 10^+12	0	5.05 x 10^-06	5.49 x 10^+21
4.27 x 10^-01	1.44 x 10^+12	1.31 x 10^+12	1.07 x 10^+12	6.67 x 10^-05	2.03 x 10^+22
8.52 x 10^-01	4.73 x 10^+11	3.11 x 10^+11	7.03 x 10^+09	6.18 x 10^-04	6.17 x 10^+22
1.28 x 10^+00	2.38 x 10^+11	6.82 x 10^+10	5.32 x 10^+09	2.43 x 10^-03	1.23 x 10^+23
1.71 x 10^+00	1.52 x 10^+11	-2.11 x 10^+10	4.54 x 10^+09	5.95 x 10^-03	1.92 x 10^+23
2.14 x 10^+00	1.14 x 10^+11	-6.14 x 10^+10	4.26 x 10^+09	1.07 x 10^-02	2.56 x 10^+23
2.56 x 10^+00	9.54 x 10^+10	-7.97 x 10^+10	4.26 x 10^+09	1.52 x 10^-02	3.06 x 10^+23
2.99 x 10^+00	8.83 x 10^+10	-8.73 x 10^+10	4.61 x 10^+09	1.77 x 10^-02	3.31 x 10^+23
3.42 x 10^+00	8.94 x 10^+10	-8.60 x 10^+10	5.33 x 10^+09	1.73 x 10^-02	3.27 x 10^+23
3.84 x 10^+00	9.94 x 10^+10	-6.85 x 10^+10	6.66 x 10^+09	1.40 x 10^-02	3.27 x 10^+23
4.27 x 10^+00	1.22 x 10^+11	-5.22 x 10^+10	9.08 x 10^+09	9.25 x 10^-03	2.39 x 10^+23
4.70 x 10^+00	1.70 x 10^+11	-2.11 x 10^+09	1.39 x 10^+10	4.76 x 10^-03	1.72 x 10^+23
5.13 x 10^+00	2.83 x 10^+11	1.15 x 10^+11	2.53 x 10^+10	1.73 x 10^-03	1.03 x 10^+23
5.55 x 10^+00	6.18 x 10^+11	4.59 x 10^+11	5.98 x 10^+10	3.62 x 10^-04	4.73 x 10^+22
5.98 x 10^+00	2.25 x 10^+12	2.15 x 10^+12	2.34 x 10^+11	2.74 x 10^-05	1.30 x 10^+22

6.41 x 10+00	4.26 x 10+12	4.23 x 10^+12	4.76 x 10+11	7.61 x 10-06	6.85 x 10^+21

Position

In this graph, the sun is approximately at the origin of the graph. Halley's Comet has an exceptionally eccentric elliptical orbit and be 100 times farther away from the sun at Apoapsis (farthest distance) compared to periapsis (closest approach).

Halley's Comet travels much faster when it is closer to the sun.

Force vs. Distance
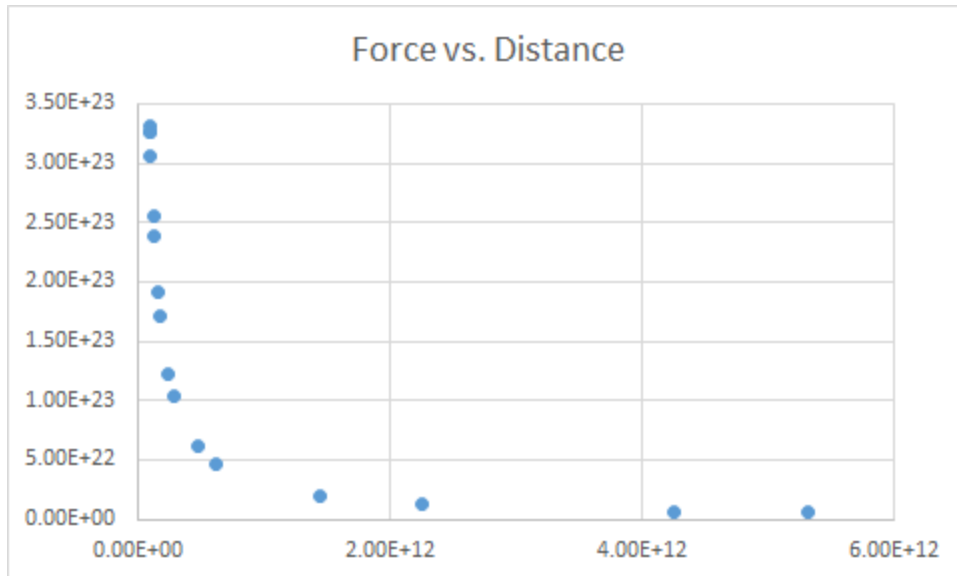
This graph illustrates an inverse squares relationship. This means that the gravitational force between two bodies is inversely proportional to the square of the distance between them.

Conclusion:

This lab was <u>mostly</u> worth it. The first thing we got rid of were the "Sports Balls", since 1- we do not own two sports balls, 2- that could be difficult to bring into a lab setting and have enough for everyone to share, and 3- we feel that we do not need any more objects to test for that section. We also think that Experiment 2 is pointless because it has literally nothing to do with mechanics; gravity is a good enough example of an inverse square law, we don't need any more examples. We both thought that Experiment 3 was worthwhile and had educational value.

Lab 9 - Conservation of Energy

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Abstract:

The law of conservation of energy states a well known fact. Energy cannot be created or destroyed but rather can only be transformed into different forms (this is a summation of the first law of thermodynamics). The most common energy transfer to study in physics is that of potential energy and kinetic energy. When you raise something, you are doing work on it and giving potential energy. When it is dropped, that potential energy is lost and transformed into kinetic energy. The law of conservation of energy has wide implications in all of the fundamental sciences.

Introduction:

In this lab, students will investigate changes in energy, and how energy is conserved in a process. Students will also use a spring to measure force over distance and calculate the work done on/by a spring. This lab also includes a data table that students can analyze and use to calculate potential and kinetic energy, also showing that energy is conserved.

Materials and Methods:

Experiment 1

Place a ruler on a table and out the spring next to the ruler so that the first coil of the spring is set at 0 cm on the ruler. Hold the spring by the last few coils and pull on the other side of the spring with the spring force scale. Pull the spring to lengths of 5, 10, 15, 20, 25 cm and measure the force at each length.

Experiment 2

Measure a distance of 0.5 m above a flat hard surface, mark this distance. Drop the ball from this height and see how high it goes after its first bounce. Obtain at least three heights.

Experiment 3

Analyze the given data table in Mircosoft Excel.

Pre-Lab Questions:

1. a) $(\frac{1}{2})kx_f^2$
    b) $(\frac{1}{2})kx_f^2$

2. a) 7.668 m/s
    b) 4.9 J
    c) 6.26 m/s

3. a) A: max potential B: max kinetic C: mostly potential, some kinetic D: max kinetic E: some potential, some kinetic F: max kinetic
    b) The kinetic energy goes from a maximum to near zero while the potential energy goes from zero to almost a maximum.
    c) If Point C was either the same height as or higher than Point A, the cart would stop at Point C.
    d) Some energy goes into heating the air and tracks through air resistance and contact with the tracks.

Results:

Table 1: Spring Scale Force Data

Force (N)	Distance, x (m)	Force$_{avg}$ (N)	ΔDistance, Δx (m)	Work (J)
0	**0**	-	-	-
-	-	0.075	**0.05**	0.00375
0.15	**0.05**	-	-	-
-	-	0.225	**0.05**	0.01125
0.30	**0.10**	-	-	-
-	-	0.375	**0.05**	0.01875
0.45	**0.15**	-	-	-
-	-	0.525	**0.05**	0.02625
0.60	**0.20**	-	-	-
-	-	0.65	**0.05**	0.0325
0.70	**0.25**	-	-	-
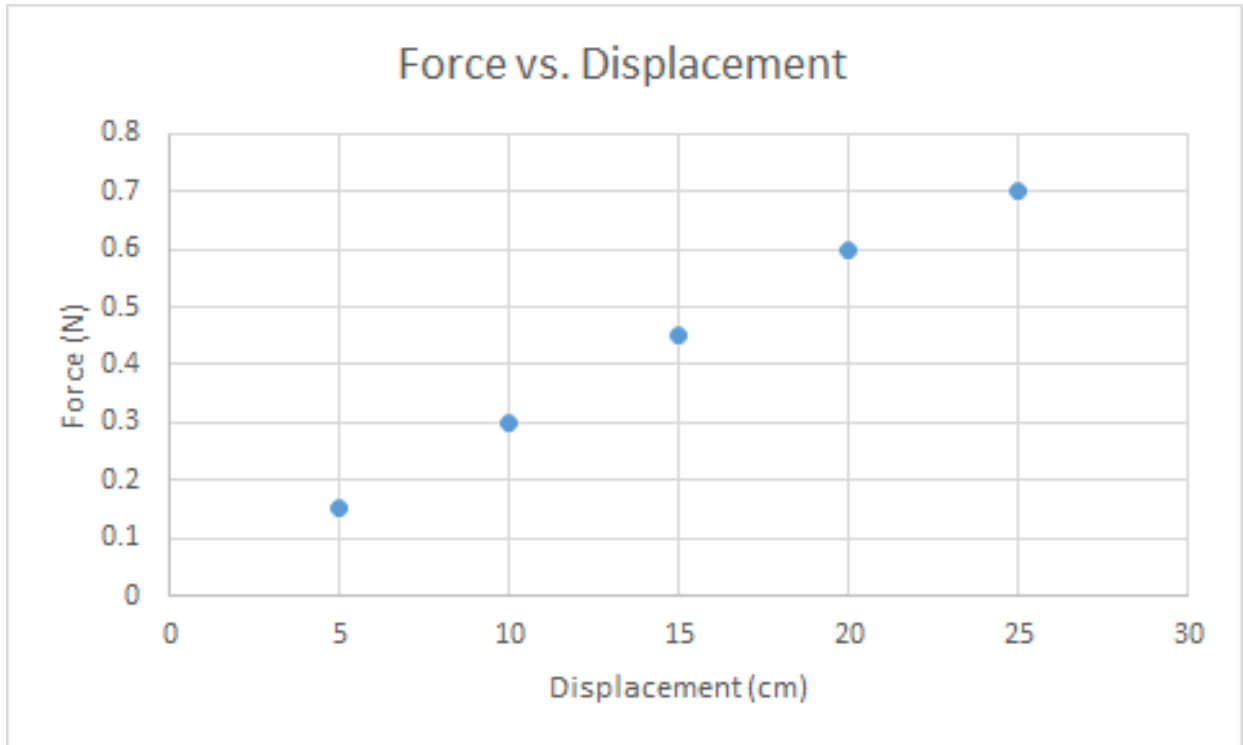
Table 2: Bounce Back Height for Various Objects

Ball Type	Trial 1	Trial 2	Trial 3	Average Height (m)
Ping Pong Ball	0.32 m	0.30 m	0.32 m	0.313

Table 4: State of Energy at Various Points in Motion

Ball Type	$PE_{0.5 \text{ meters}}$	KE_{before} bounce	$PE_{new \, max}$ height	TE	$KE_{after \, bounce}$
Ping Pong	0.01323 J	0.01323 J	0.008282 J	0.004948	0.008282 J

Note that in this table TE is not Total Energy but is Thermal Energy, the energy lost between bounces.

Table 5: Dropped Ball Data

Time (s)	Ball Position (m)	Ball Velocity (m/s)	Potential Energy (J)	Kinetic Energy (J)	Total Energy (J)
0.00	5.00	-	24.5	0	24.5
0.05	4.99	-0.2	24.451	0.01	24.461
0.10	4.96	-0.6	24.304	0.09	24.394
0.15	4.89	-1.4	23.961	0.49	24.451
0.20	4.78	-2.2	23.422	1.21	24.632
0.25	4.69	-1.8	22.981	0.81	23.791
0.30	4.54	-3	22.246	2.25	24.496
0.35	4.40	-2.8	21.56	1.96	23.52
0.40	4.22	-3.6	20.678	3.24	23.918
0.45	4.00	-4.4	19.6	4.84	24.44
0.50	3.80	-4	18.62	4	22.62
0.55	3.50	-6	17.15	9	26.15
0.60	3.26	-4.8	15.974	5.76	21.734
0.65	2.93	-6.6	14.357	10.89	25.247
0.70	2.60	-6.6	12.74	10.89	23.63
0.75	2.23	-7.4	10.927	13.69	24.617
0.80	1.88	-7	9.212	12.25	21.462
0.85	1.46	-8.4	7.154	17.64	24.794
0.90	1.05	-8.2	5.145	16.81	21.955
0.95	0.58	-9.4	2.842	22.09	24.932
1.0	0.11	-9.4	0.539	22.09	22.629

Postlab Questions

Experiment 1

1. Force vs. Displacement
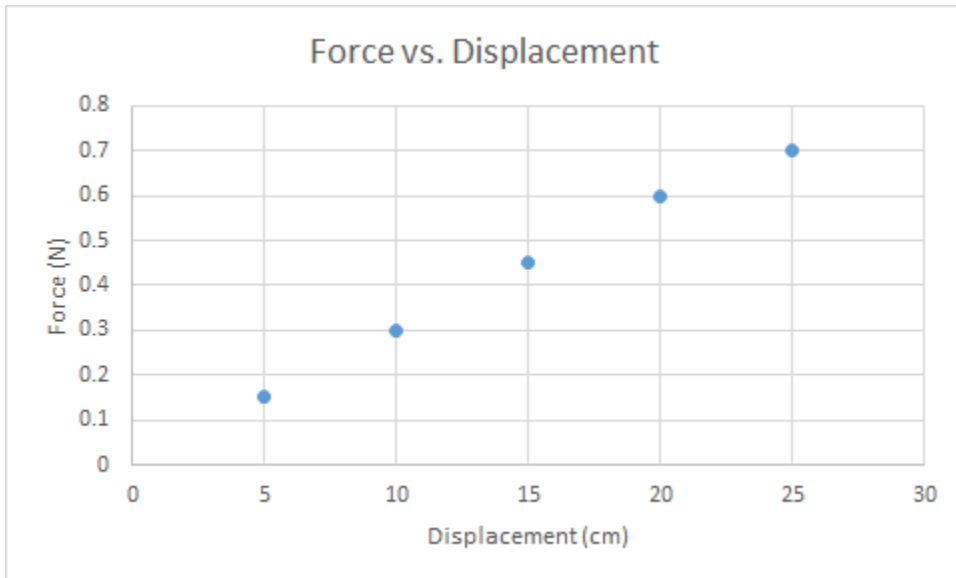
2. Calculate Work for Table 1

3. Calculate average force in table 1

4. The results of question two are the same as the total work. Integration is a linear operator so adding the integral of each section is the same as the integral of the whole thing. The total work done by the spring is = 0.0925 J

Experiment 2

1. Fill out table four.

2. Right before the first bounce the speed is = 3.13 m/s
   Right before the second bounce the speed is = 2.48 m/s

Experiment 3

1. Graph of Energy over Time

Energy of the Dropped Ball System vs. Time

Potential Energy
Kinetic Energy
Total Energy
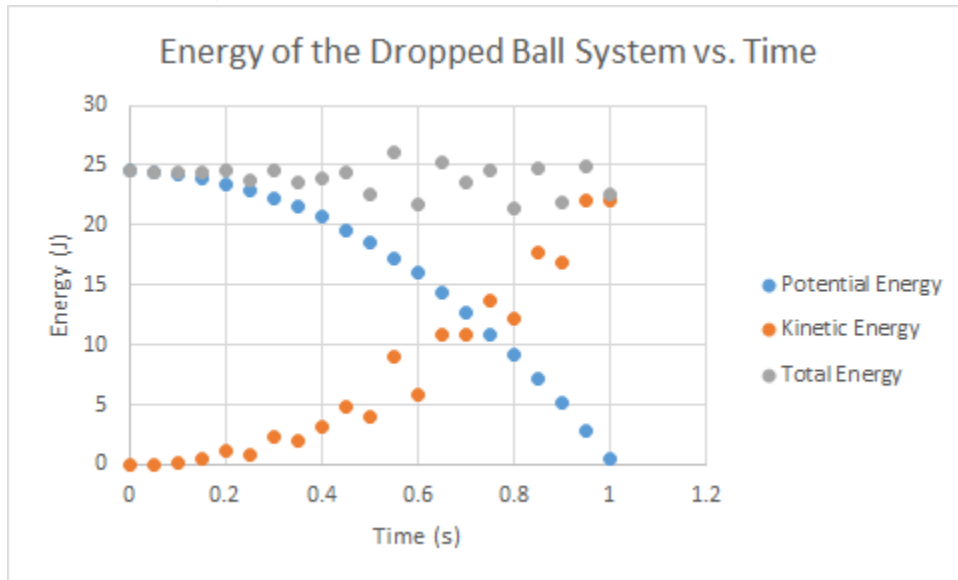
2. This graph depicts a stable parabolic decrease in potential energy and a less stable parabolic increase in kinetic energy. The total energy of the system remains relatively constant.

3. The limitation of the leapfrog method is that the method does not calculate instantaneous velocity but the average velocity over intervals. The leapfrog method is comparable to using Riemann sums rather than Integrals.

Conclusion:
Overall, this lab was worth our time. The only part that proved to be somewhat difficult was measuring the bounce height of the ping pong ball since you don't have much time to record the height. We could try using sensors if possible/necessary to do this form us. This is also another lab that requires the use of "Sports Balls", which, if we really wanted to, we could just purchase tennis balls and golf balls to use for all labs that require these. Additionally, the third experiment would be equally effective as homework and need not be done in a lab setting.

Lab 10 - Conservation of Momentum
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Sophia Leitzman, smleitzman@wpi.edu

Abstract:

The law of conservation of momentum is an important aspect of introductory physics and continues to have modern day applications. For example, spacecraft propel themselves through space using the law of conservation of momentum. The fact that momentum is conserved is a fundamental part of our greater understanding of physics.

Introduction:
In this lab students will conduct tests to explore elastic and inelastic collisions. Such as having marbles collide and analyzing graphs of either situation.

Materials and Methods:
Utilizing two rulers and a few marbles, set up a track for the marbles using the rulers by placing the rulers parallel to each other.
Conduct several tests on the marbles. Try having some marbles stationary in the middle and flicking a marble at them or flicking marbles so they collide head on. Also try and mix and match the number of marbles flicked from each side in each experiment.

Pre-Lab Questions:
1.
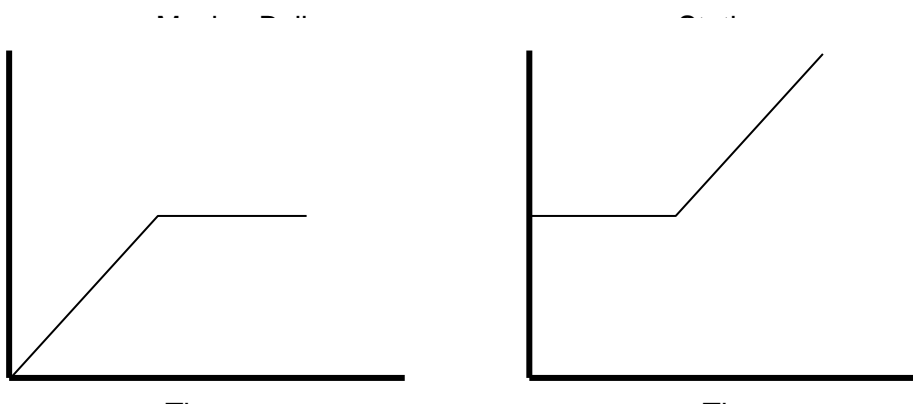
   a.
   b. The momentum from the momentum was successfully transferred into the stationary ball, as shown by the moving ball becoming stationary and the stationary ball moving.

2. $p_{total} = 2mv$, $KE = mv^2$
3. In a perfectly elastic collision, each individual marble will have its own momentum, meaning that the first marble to hit will put the furthest one away into motion before the second marble to hit has the chance to transfer its momentum to the opposite end of the line.

Results:

Experiment 1: Conservation of Momentum

Table 1: Collision Data - Moving and Stationary Marbles

Number of Flicked Marbles	Number of Stationary Marbles	Number of Marbles that Leave the Runway
1	4	NA
2	3	NA
3	2	NA
4	1	NA
1	2	1

Table 2: Collision Data - Moving Marbles

Number of Marbles on the Right Side of the Runway	Number of Marbles on the Left Side of the Runway	Number of Marbles that Leave the Right Side of the Runway	Number of Marbles that Leave the Left Side of the Runway
1	1	1	0
1	2	2	1
1	3	NA	NA
1	4	NA	NA
2	2	NA	NA
2	3	NA	NA

Post Lab Questions
1. The marbles exhibited elastic collisions in each experiment. There is not much frictional loss and all of the marbles were of the same mass. The opportunities to

dissipate kinetic energy in the system were minimal.

2. When one marble hit the line of marbles, only one marble shot off the other end. The momentum of the first marble was conserved and carried through the line to the last marble.

3. Assuming negligible frictional loss, the speed of the marble coming off the end of the line was the same as the speed of the first marble when it hit the line of marbles.

4. N/A we only had three marbles, however in the trial where two marbles had a head on collision with one marble, the middle marble would continue on its path, and each of the end marbles travelled in the reverse direction. Momentum was transferred through the middle marble but its own momentum was not changed much.

5. When both marbles were flicked heading toward each other they collided and then travelled in opposite directions.

6. If you were to slowly roll a marble and then roll another marble faster such that it catches up to and collides with the first marble, it is most likely that the second marble will slow to the speed of the first and the first marble will speed up to the speed of the second.

Experiment 2: Egg Drop
Table 3: Egg Drop Data

Paper Placement	Egg Observations
No Paper	Did not break
3 Sheets at the Top of the Bowl	Did not break
3 Sheets Spaced About 2 to 3 cm Apart	NA

1. The egg never broke regardless of the design.
2. We wouldn't know.
3. The net absorbs their weight by providing a force on them for a long period of time, slowing them down as they fall.
4. You bend your knees to slow down your fall, similar to the circus net.

<u>Graphical Analysis of Collisions</u>
Part 1
In the first graph the collision was perfectly inelastic, the balls were travelling in opposite directions. When they collided they began travelling in the same direction with the same speed, they stuck together.

The second graph shows a perfectly elastic collision. All of the velocity of the ball that was moving was imparted onto the ball at rest. The ball moving initially came to rest and the ball initially at rest ended up with the same velocity that the first ball had.

This is an inelastic collision. This graph describes a ball in motion hitting a ball at rest. Some but not all of the velocity of the first ball is imparted on the second. Both balls are moving but they did not stick together.

Part 2
   1.

Momentum Variables	Object b	Object r
m (kg)	3	1
v_i (m/s)	2	-2
v_f (m/s)	1	1

   2.

Momentum Variables	Object b	Object r
m (kg)	2	4
v_i (m/s)	4	-2
v_f (m/s)	-4	2

<u>Conclusion:</u>
The egg portion of this experiment is not very useful. However, the marbles portion has educational value and can be conducted pretty quickly and easily. The graphical portion, while not actually having an experimental procedure was also useful. It will help develop graphical interpretation skills and is additional practice to help students visualize what is happening in a graph. Additionally, if there were more than three marbles (across all the experiments there are three in the eScience Lab Kit) to work with this lab would be much better.

Lab 11 - Torque and Static Equilibrium

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Abstract:

Torque is the application of force to induce rotation in an object. Just as all of the translational equations have analogous rotational equations, torque, in rotational physics, is analogous to force in translational physics. A major application of torque is its application to static equilibrium. In a static situation, like force, the net torque is zero. This allows a student to introduce new equations to a system that help solve the system.

Introduction:

In this lab students will explore the applications of torque and static equilibrium. Students will discover how torque is related to distance and static equilibrium by pushing on a door at different distances and analyzing a couple static equilibrium situations.

Materials and Methods:

Door   Clay   Ruler   Pencil   10-N Spring Scale

Experiment 1

      Qualitatively analyze the differences in force needed to open a door at different distance from its hinge.

Experiment 2

      Cut the playdough into four equal masses. Place these masses at various locations along the ruler and qualitatively analyze how the moment of inertia is affected.

Experiment 3

      Place a ruler on a pencil near the edge of a table so that the end of the ruler is over the edge of the table and the 15 cm mark of the ruler sits on the pencil reasonably close to the edge of the table. Place the 250 gram mass on the end of the ruler on the table. Hook the 10-N spring scale different distances from the fulcrum of the ruler (the pencil/15 cm mark) and measure how much force is needed to just lift the mass of the table and make the ruler parallel to the ground.

Pre-Lab Questions:
1. This prelab question is vague and unclear. I can see students getting confused about it very easily.
2. If a ring and cylinder had the same mass and radius, the cylinder would reach the bottom first. This is because it has a smaller moment of inertia and therefore is less resistant to acceleration.
3. $T_1 - T_2 = 0$
   $R_1F_1 - R_2F_2 = 0$
   $R_1mg - R_2F_2 = 0$

Results:
Experiment 1

Table 2: Force Applied to a Door at Varying Distances from the Hinges

Distance from handle to hinges: 91 cm

Push Distance (cm)	Observations
30	More Difficult to open door
61	Some resistance pushing the door open
91	Door was relatively easy to push open.

Postlab Questions
1. As the force applied got farther from the hinges, it became easier to push the door. Less force was needed to move the door and when the same force was applied, the door moved fastest farthest from the hinges.
2. If you used the same force at each point along the door, the torque would be least closest to the hinges and would be greatest by the door handle.
3. The moment of inertia for a rod about its end is $(mL^2)/3 = 3.333$ kg m^2
   If a 50 N force is applied at 20 cm and 1 m
   a. Applied at 20 cm the angular acceleration = Torque/Moment = 3 rad/s^2
   b. Applied at 1 m the angular acceleration = Torque/Moment = 15 rad/s^2
4. Most door handles are farthest as possible from the hinges because that is where a small amount of force can generate a large torque on the door.

Experiment 2

Table 3: Rotating Clay at Different Distances From an Axis

Amount of Clay and Position on Ruler	Observations
Two equal pieces of clay on each end of the ruler	The ruler was very resistant to change in motion. A little hard to move.

One piece of clay on each end of the ruler	The ruler wasn't hard to move
One piece of clay on each side of the ruler halfway between the axis and end of the ruler	The Ruler was very easy to move, not much resistance.

Post Lab Questions
1. It felt like about half as much effort was needed to rotate the ruler when there was half as much mass on.
2. The largest moment of inertia was produced by the arrangement with two lumps of clay on each end. The smallest moment of inertia was produced when one lump of clay was placed halfway to the end on each side.
3. There is no step 10 in the lab but,
   If the masses are located at the halfway from the center to the end on each side, you would need four times the mass to get the same moment of inertia as having mass on the ends.
4. Moment of inertia has an L^2 term. Therefore halving the mass introduces a ¼ term. You need 4x more mass to compensate for this.

Experiment 3
Table 4: Force Applied at Varying Distances on a Lever
R_2 Distance (m): 0.15

R_1 (m)	F_1 (N)	T (mN)	F_1 (N) Theoretical	Percent Error (%)
0.05	7.2	360	7.35	2.04
0.06	6.1	366	6.125	0.41
0.07	5.2	364	5.25	0.95
0.08	4.5	360	4.59	1.96
0.09	3.4	306	4.083	16.73
0.10	3.0	300	3.675	18.37
0.11	3.0	330	3.34	10.18

Post-Lab Questions
1. The required force decreased as R_1 increased.

2. "Determine the applied torque at each distance. Record the applied torque in Table 4."
3. "Use your answer from Pre-Lab Question 3 to calculate the theoretical force applied at each R_1 distance. Record the theoretical force in Table 4."
4. "Calculate the percent error between the theoretical force and the actual force applied to the lever at each R_1 distance. Record the percent error values in Table 4."
5. Although our experimental torque was not very consistent, it is supposed to remain at about the same value throughout the experiment.
6. Force vs. Radius
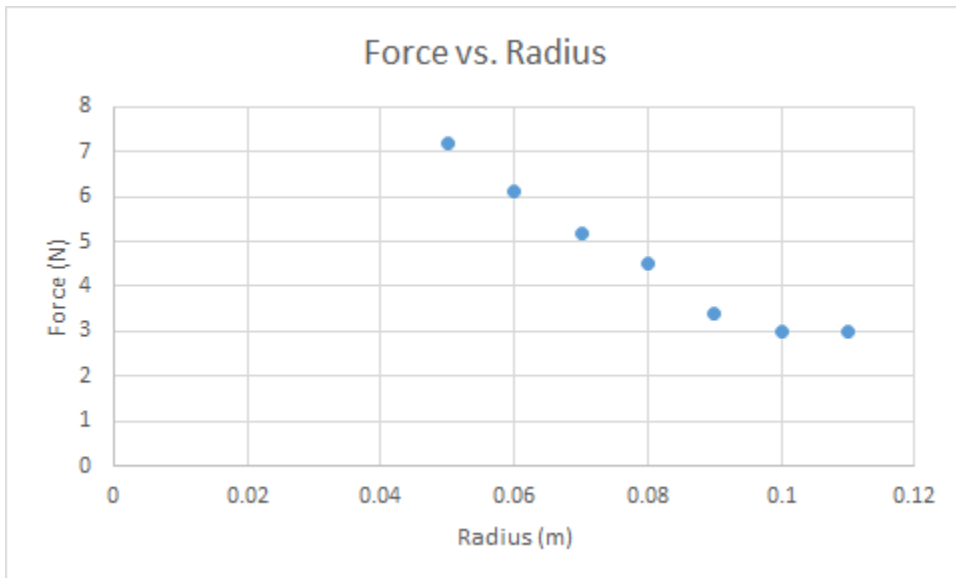
7. I would expect F_1 to be halved because the torque required to lift it would also be halved.

Conclusion:

These experiments were easy and of reasonable educational value. Each experiment was not very hard to set up and involved an important component of torque and static equilibrium. We have no major issues with any of these experiments and recommend running all three.

Appendix B - Laboratory Experiments Created by or Altered by Prof. Nancy A. Burnham PhD

During the course, it was found that the laboratory procedures provided in the eScience Kits™ were insufficient for the course. Included in this appendix are the labs created by Prof. Burnham, or the altered versions of the eScience Kits™ procedures. Worksheets 2, 7, and 12 were available to students in Microsoft Excel for them to input values and see the results.

Worksheet on averages and standard deviations

Your name:

Measurement	Centimeters [cm]	Time [s]
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Your average reaction time =
Your standard deviation =

Three other people's results

Person	Name	Average	Std Dev
1			
2			
3			

Respond with a sentence or two individually, as homework.
Considering standard deviation, how would you define "same" or "different" times?

Cosidering standard deviation, how do you rank the reaction times of the four students?
Would your ranking be any different if you ignored standard deviation? Explain briefly.

To be done individually, as homework. This page to be scanned and submitted as a PDF at our Canvas site.

Illustrate by sketching by hand a bar chart of the four results, one bar per student, with error bars representing the standard deviations. Label the bars with the names.

What is the acceleration due to gravity?

Measurement number	Time on computer [s]	Time of drop [s]	Position of ball [m]	Velocity [m/s]	Acceleration [m/s²]
1					--
2					--
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

Average acceleration from slopes =

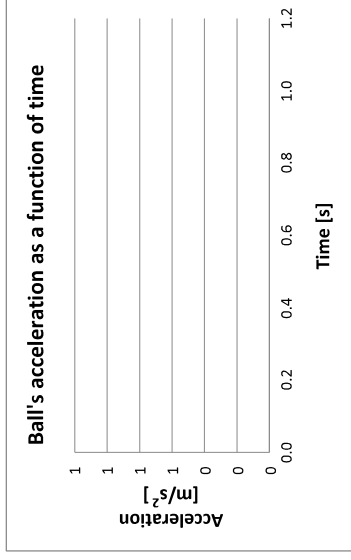Standard deviation of acceleration =

Instructions:

1 For ease of grading, please assume a coordinate system in which the positive direction is up.
   Record data approximately every 50 ms and estimate the ball's position to the nearest 5 cm.

2 Calculate velocity and acceleration for each time interval, as well as the average acceleration and its standard deviation.
   Report your value below for the acceleration from the slopes using the form (Average ± Std. Dev) Units.

3 On each of the plots below, fit an appropriate trendline and display its equation and R-squared value on the chart.
   From the y(t) plot, determine the acceleration due to gravity from the trendline's equation.
   VERY roughly, the acceleration's standard deviation is (1-R^2)* |Acceleration|.
   Report your value below for the acceleration from the trendline using the form (Average ± Std. Dev) Units.

4 **Your results and questions:**
   Your result for the acceleration due to gravity from the slopes:
   Your result for the acceleration due to gravity from the y(t) trendline:
   Which result is better?
   What are the geometric shapes of the y(t) and v(t) curves?
   (Your a(t) curve is likely to be very noisy.)

Ball's position as a function of time

Ball's velocity as a function of time

Ball's acceleration as a function of time

Projectile Motion

Typically, a **projectile** is any object which, once projected, continues in motion by its own inertia and is influenced only by the downward force of gravity. This may seem counter-intuitive since the object is moving both horizontally and vertically, but gravity (an applied force) acts only on the vertical motion of the object. The term **inertia** describes an object's resistance to external forces which could affect its motion (both velocity or directionality). When there are no external forces acting upon an object, it will continue to travel in a straight line at a constant, linear velocity.
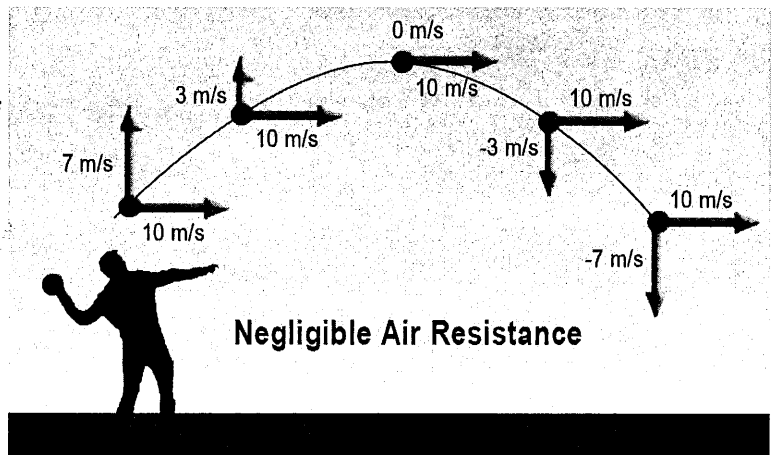
Figure 2: The path of a projectile in the absence of air resistance is a perfect parabola. The horizontal component of velocity is 10 m/s throughout the object's motion.

As shown in Figure 2, the projectile with horizontal and vertical motion assumes a characteristic parabolic trajectory due to the effects of gravity on the vertical component of motion. If air resistance is neglected, there are no horizontal forces acting upon the projectile, and thus no horizontal acceleration. It might seem surprising, but a projectile moves at the same horizontal speed no matter how long it falls!

? Did You Know...

Cannons on Navy battle ships can fire at objects that are farther than fifteen miles away. The curvature of the Earth makes it impossible to see that far in the distance. That means that the cannons fire projectiles at objects they cannot physically see!
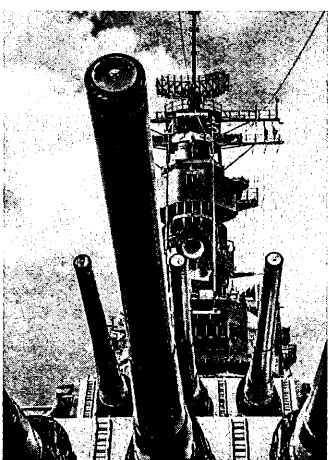
Since projectile motion can be resolved into two independent directions, 1-D kinematic equations can be applied to both components of the motion separately. The kinematic equations will allow you to solve for different aspects of a projectile's flight, its **height** (vertical), **range** (horizontal), and time of flight. Applying 1-D kinematics results in two sets of equations for 2-D motion:

Height	Range
$y_f = v_{0,y}t - 1/2gt^2$	$x_f = v_{0,x}t$
$v_{f,y} = v_{0,y} - gt$	
$v_{f,y}^2 = v_{0,y}^2 - 2gy$	

The x and y subscripts for velocity refer to the component of velocity in the x and y directions. These two sets of equations (height and range) also incorporate time because the time of flight for the projectile motion is the same for both the vertical and horizontal motions. Notice that there is only one equation for range, while there are three equations for height! This is due to the fact there is no acceleration in the horizontal direction. You may often be required to find the time of flight using the height equations in order to determine the range of the projectile.

Your name:

Launch Angle

If the projectile is fired at an angle, the range is a function of the initial **launch angle**, θ, the launch velocity and the force of gravity. Using algebra, you can derive the following expression from the kinematics equations:

$$R = \frac{v^2 \sin(2\theta)}{g}$$

It is important to remember that in many cases, air resistance is not negligible (Figure 3) and affects both the horizontal and vertical components of velocity. When the effect of air resistance is significant, the range of the projectile is reduced and the path the projectile follows is not a true parabola.
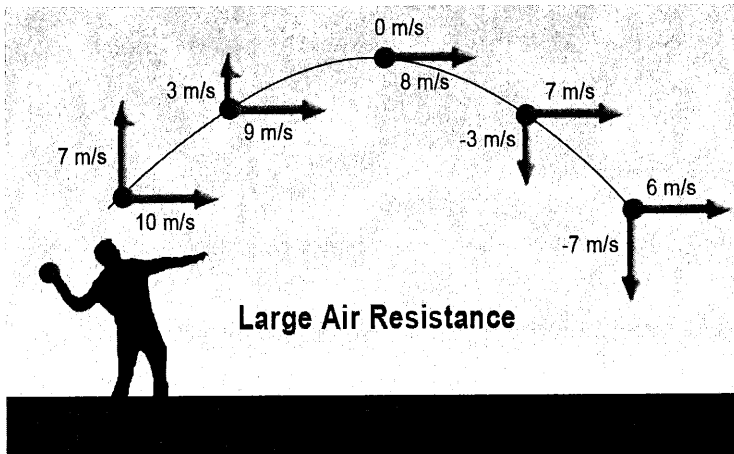
Figure 3: With air resistance, the trajectory looks like a "squashed" parabola, and the range of the object's flight is noticeably affected.

Pre-Lab Questions

1. In one of your experiments, you will roll a marble down a ramp to provide an initial horizontal velocity. Suppose you start the marble at rest ($v_o = 0$ m/s) and it travels a distance of, d, down the ramp. Use 1-D kinematics to predict the velocity of the ball (v_f) at the bottom of the ramp. Record your answer in variable form (you will calculate the velocity with magnitudes when you perform the experiment).

2. Use the kinematic equations to derive a general equation for the time it takes a ball dropped from rest at vertical height, h, to reach the ground.

3. Use the result from Pre-Lab Question 2 to formulate a general equation for the distance travelled by a projectile that is rolling off a table of height, h, with a horizontal speed, v_{ox}.

4. The range of projectiles is dependent on the velocity and angle of the launch. Use the kinematic equations to prove the range of a projectile launched at velocity, v, and angle, θ, is equal to $R = \dfrac{v^2 \sin(2\theta)}{g}$.

   Hint: The velocity at the beginning and end of the motion has the same magnitude, but opposite direction.

5. Prove that launching a projectile at 45° provides the largest range.

   a. Write the range as a function of θ.

   b. Take the derivative of the range with respect to θ and find the maximum angle.

Experiment 1: Distance Traveled by a Projectile

In this experiment, you will use kinematic equations to predict the range of a projectile set in motion. To do this, you will roll marbles down a ramp and off a table to observe vertical and horizontal motion.

⚗ Materials

Sheet of Carbon Paper	Sheet of Printer Paper
Fishing Line	Tape Measure
1 Fishing Sinker	*Pencil
Masking Tape	*Table
1 Marble	
1 Protractor	*You Must Provide
1 Ramp	

Note: You will need to construct the ramp (provided in your lab kit) prior to beginning the experiment. To do this, complete the following steps:

Ramp Set-Up (Figure 4)

1. Separate the two pieces; one long and narrow piece to provide the ramp, and one wider piece to provide the base.

2. Fold the wider section along the perforations to form a triangular stand.

3. Insert the tab through the slot to construct a triangular stand (Figure 4, Part 2).

4. Insert the tab on long, narrow piece into one of three slots on the triangular stand. Different slots correspond to different inclines.
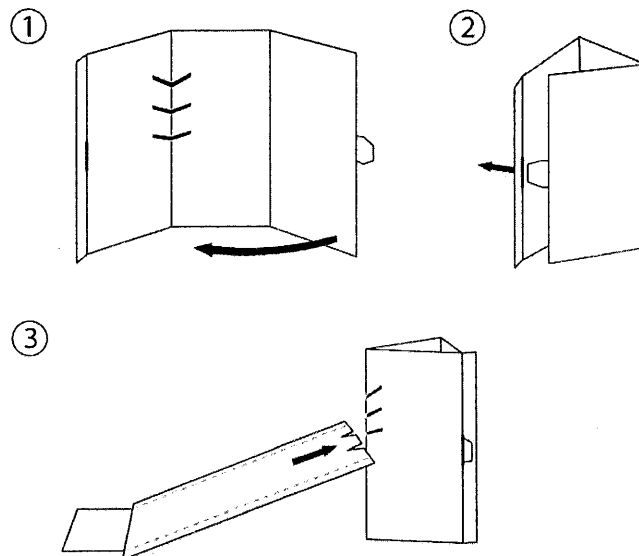
Figure 4: Ramp set-up diagram.

Procedure

1. Find a table upon which to perform the experiment. Place the ramp so that its bottom edge is positioned at the edge of the table. You will be rolling marbles down the ramp and off the table in this experiment.

2. Use a protractor to measure the incline of your ramp. Record the angle of the incline in Table 1.

3. ~~Use a pencil to mark~~ *Choose* three different locations on the ramp at which you will release the marble. This will ensure the marble achieves the same velocity with each trial.

   Hint: Use locations near the top, middle and bottom of the ramp.

4. Create a plumb line by attaching the fishing sinker to the fishing line.

5. Hold the string to the edge of the table, and use a piece of masking tape to mark the spot at which the weight touches the ground.

   Note: The length of the plumb line will help you measure the exact distance from the edge of the ramp to the position where the marble lands.

6. Begin the experiment by releasing the marble from the first position you marked on the ramp in Step 3. In other words, release the marble from the highest position which you marked on the ramp.

7. Carefully observe where the marble hits the ground and place a piece of white printer paper at that location. Secure the paper to the ground with a small piece of masking tape. Make sure the paper can moved when the different ramp positions are tested. Try to center the printer paper over the spot where the marble hit the floor.

8. Set the carbon paper on the printer paper so that the light side faces up. When the marble hits the carbon paper, it will leave a mark on the printer paper.

9. Place the marble at the same drop mark you just tested and release it.

10. Use the tape measure to measure the distance the marble traveled. Do this by measuring the distance between the masking tape mark where the fishing sinker met the floor and the carbon mark on the printer paper. Record the distance in Table 1.

11. ~~Once you have recorded the distance in Table 1, put an "X" over the mark you just measured so you do not reuse it.~~

12. Repeat Steps 9 - 10 three more times and record your data in Table 1.

13. Repeat Steps 6 - 12 for the remaining two ramp distances you marked in Step 2. Record your results for the second ramp distance in Table 2, and the third ramp distance in Table 3.

14. Save the printer paper. The unused side will be used in the next experiment (if assigned).

Work together with your lab partner to fill in the 3 tables.

Table 1: Range and Velocity of Projectile at Ramp Distance 1	
Ramp Incline (degrees)	
Ramp Distance (m):	
Trial	**Measured Distance (m)**
1	
2	
3	
4	
Average ±SD	

Table 2: Range and Velocity of Projectile at Ramp Distance 2	
Ramp Distance (m):	
Trial	**Measured Distance (m)**
1	
2	
3	
4	
Average ±SD	

Table 3: Range and Velocity of Projectile at Ramp Distance 3	
Ramp Distance (m):	
Trial	**Measured Distance (m)**
1	
2	
3	
4	
Average ± S.D.	

Post-Lab Questions:

1. Use your predictions of velocity (v_f) and range from the Pre-Lab Questions, and the data recorded from your experiment to complete Table 4.

Table 4: Velocity and Range Data for all Ramp Distances				
Ramp Distance (m)	**Calculated velocity (m/s)**	**Predicted Range (m)**	**Average Actual Range (m)**	**Percent Error**

2. Compare your predictions to the observed data. Identify and explain at least two reasons for the difference between them.

3. If you were to fire a paintball pellet horizontally, at a set height, and at the same time drop an identical pellet from the same set height you fired from the paintball gun, predict which pellet would hit the ground first. Explain your reasoning.

Answer Questions 1-5 individually.

4. If the ramp is altered so that the marbles have twice their initial velocity right before leaving the ramp, predict how this would change the total distance traveled by the marbles. Cite the kinematic equations (or variations of them) to support your answer.

5. Describe the acceleration of the marble after it leaves the ramp.

Experiment 2: Squeeze Rocket™ Projectiles

In this experiment, you will investigate how the launch angle of a projectile affects the distance it travels.

Procedure

1. Place the unused side of the printer paper face up on a flat work space and secure with a piece of masking tape.

2. Use a pencil to mark the spot in the middle of the printer paper. This is the where the rockets will be launched every trial.

🜊 Materials

Masking Tape	Stopwatch
Mirror Support	Tape Measure
Printer Paper	*Pencil
Protractor	
4 Squeeze Rockets™	*You Must Provide
1 Squeeze Rocket™ Bulb	

3. Stabilize a protractor so that it stands up vertically by inserting the flat part of the protractor into the mirror support. Using a protractor, align the rocket to a 90° angle. In other words, it should be vertically directed upward.

4. Load a Squeeze Rocket™ onto the bulb.

    <u>Note</u>: The Squeeze Rocket™ is a trademarked product name. The "rocket" itself does not use a self-

Session 4 worksheet on equilibrium   **Your name:**

Collect data and do the analysis with your lab partners, but please do the sketches and questions individually. Submit this worksheet as a PDF.

1. <u>Collect data:</u> Three forces of magnitudes differing by at least 1 N. Force #1 is defined as being along the +x-axis (zero degrees). Units!
2. <u>Analysis:</u> Convert the force vectors into **i-j** form. Sum the components and convert them back into magnitude and direction of the sum.

Force	Magnitude [ ]	Direction [ ]	In i-j form [ ]
1		0	
2			
3			
Sum			
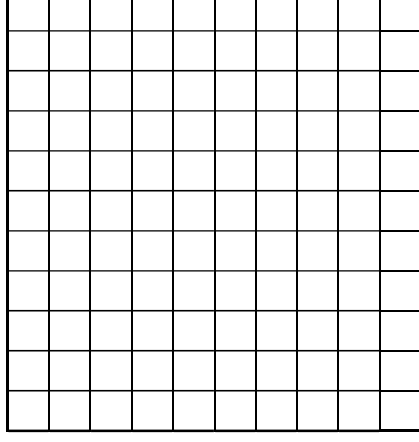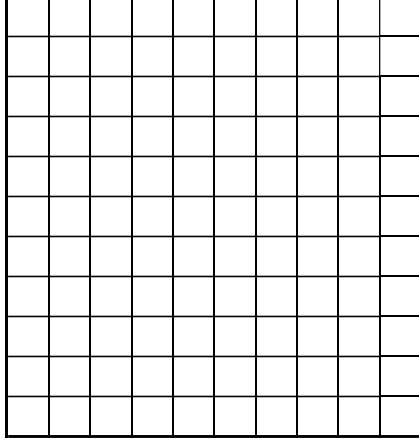
3. <u>Sketch</u> the three forces (to scale) as vectors on the two grids (with scaled and labeled axes) in two ways, once with all of their tails at the origin, and once in the "tip-to-tail" presentation.

4. <u>Questions:</u> What should the forces sum to? If the sum is different than you expect, give reasons why.

You likely have a gap between the tip of the third and the tail of the first vector in your tip-to-tail plot. What does the gap represent?

Experiment 3: Newton's Second Law and the Atwood Machine

This experiment will demonstrate the mechanical laws of motion using a simple assembly named the Atwood machine, similar to that used by Rev. George Atwood in 1784, to verify Newton's Second Law.

⚗ Materials

~~Masking Tape~~	Stopwatch
2 Paperclips	String
Pulley	~~Tape measure~~ *meterstick*
~~5 N Spring scale~~	15 Washers
clamp	*Wooden dowel*

Procedure

Part 1 *Clamp the wooden dowel to the table. Hook the pulley over it.*

1. ~~Support the pulley so that objects hanging from it can descend to the floor. Do this by tying a short piece of string to one of the pulley hooks. Use a piece of masking tape to secure the string to a table top or door frame so that the pulley hangs plumb (Figure 7).~~

    ~~Note: A higher pulley support will produce longer time intervals which are easier to measure.~~

2. Thread a piece of string through the pulley so that you can attach washers to both ends of the string. The string should be long enough for one set of washers to touch the ground with the other set near the pulley. (You may attach the washers using a paperclip ~~or by tying them on~~).
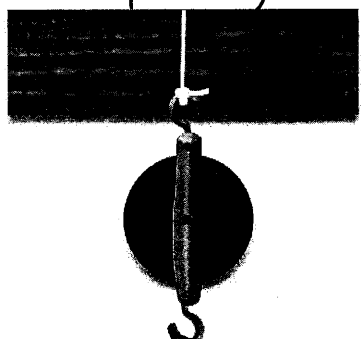
Figure 7: Pulley set up reference for Step 1.

$m_{15} = 50.7g$

3. ~~Use the spring scale to weigh the set of 15 washers. Divide the total mass by 15 to find the average mass of a washer. Record the total mass of the washers and average mass of one washer in Table 5.~~

4. Attach seven washers to each end of the string.

5. Observe how the washers on one side behave when you pull on the washers on the other side. ~~Answer Post-Lab Question 1 based on your observations.~~

6. Add the remaining washer to one end of the string so one side of the string has seven washers (M_1), and the other has ~~eight~~ washers attached to it (M_2).

7. Determine the approximate mass of M_1 and M_2. Record their masses in Table 6. *six X*

8. Place M_1 on the floor. Use the ~~tape measure~~ *meter stick to* measure the height that M_2 is suspended while M_1 is on the floor. Measure the distance M_2 will fall to the floor when you release the lighter set of washers. Rec-

ord the distance in Table 6.

9. Time how long it takes for M_2 to reach the floor. Repeat Steps 7-8 four more times (five times total), recording the values in Table 6. Calculate and record the average time in Table 6.

10. Calculate the acceleration (assuming it is constant) from the average time and the distance the washers moved.

Part 2 **Add**

1. ~~Transfer~~ one washer, so that there are six on one end of the string (M_1) and ~~nine~~ **eight** on the other (M_2).

2. Determine the approximate mass on each end of the string. Record the mass values in Table 7.

3. Repeat Steps 7 - 9 of Procedure 1. Record data in Table 7.

Table 5

Table Motion Data	
Mass of 15 Washers	**Average Mass of**

Table 6: Procedure 1 Motion Data	
Mass of M_1 (7 washers):	
Mass of M_2 (8 washers): 6	
Height (m):	

Trial	Time (s)
1	
2	
3	
4	
5	
Average ± SD	
Average Acceleration (m/s²)	

predicted acceleration :

% error :

Table 7: Procedure 2 Motion Data

Mass of M₁ (6 washers):

Mass of M₂ (8 washers):

Height (m):

Trial	Time (s)
1	
2	
3	
4	
5	
Average ± SD	
Average Acceleration (m/s²)	

Post-Lab Questions *Predicted acceleration :* _____
                    % Error _____

1. What do you observe about the motion of the washers when you give one set a downward push compared to the other set? Does it stop before it reaches the floor? Explain this behavior.

On the next page,

2. Draw a free body diagram for M₁ and M₂ in Procedure 1 ~~and M₁ and M₂ in Procedure 2~~. Draw force arrows for the force due to gravity acting on both masses (F_{g1} and F_{g2}) and the force of tension (F_T). Also draw arrows indicating the direction of acceleration, a.

3. Use Newton's Second Law to formulate an equation for each of the free body diagrams you drew in Post-Lab Question 2 (use the correct signs to agree with your drawings). Solve these ~~four~~ *two* equations for the force of tension (F_T). Record the ~~four~~ *two* equations in variable form. *and acceleration (ā). Use the expression for (ā) to calculate your predicted acceleration.*

Lab 9   Conservation of Energy

d. What causes the roller coaster train to lose energy over its trip?

Experiment 1: Work Done ~~by~~ on a Spring

In this experiment, you will investigate work done ~~by~~ on a spring.

℞ Materials

Ruler	*Internet Access
Spring	
5 N Spring Scale	*You Must Provide
*Computer	

Procedure

1. Calibrate the ~~5~~ 10 N spring scale to zero.

2. Lay the ruler on the table with the centimeter scale closest to you.

3. Place the end of the spring with the circular hook next to the ruler so that the end of the spring lines up to the 0 cm mark on the ruler (Figure 7).

Figure 7: Step 3 reference. Notice that the end of the free spring is lined up to the 0 cm mark of the ruler.

4. Hook the spring scale onto the circular hook of the spring. Make sure the Newton scale is visible so you will be able to make measurements.

5. Secure the spring by grabbing ~~10 coils~~ the end from the opposite end of the spring.

   Note: It is important that you always secure ~~10 coils~~ the end of the spring. If possible, do not let go of the spring while recording data.

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6. Pull the spring scale until the end of the spring is stretched to the 5 cm mark on the ruler. Record the force reading on the spring scale in Table 1.

7. Repeat Steps 3 - 6 for stretching distances of 10, 15, 20, and 25 cm.

Table 1: Spring Scale Force Data				
Force (N)	Distance, x (m)	Force$_{Average}$ (N)	Δ Distance, Δx (m)	Work (J)
0	0			
			0.05	
	0.05			
			0.05	
	0.10			
			0.05	
	0.15			
			0.05	
	0.20			
			0.05	
	0.25			

total work = [   ]

Note, you will finish completing Table 1 in the Post-Lab Questions section.

Post-Lab Questions

Use graph paper. (last page)

1. Create a Force vs. Displacement (stretch distances) graph. Construct your graph on a computer program such as Microsoft Excel®. If you do not have a graphing program installed on your computer, you can access one on the internet via the following links: http://nces.ed.gov/nceskids/createagraph/ or http://www.onlinecharttool.com/graph?selected_graph=bar.

Do this later. ~~Work on table now:~~
Fill in table while in lab. Indicate work on graph.
Indicate spring constant on graph.

2. ~~Using the result of Pre-Lab Question 1,~~ calculate the work done ~~by the~~ on the spring. ~~Show your work.~~

$$W = \int \vec{F} \cdot d\vec{s} = ?$$

3. The work done ~~by~~ *on* the spring can be broken down by the work done by each 5 cm stretch. Fill in the rest of Table 1 to calculate the average force applied by the spring over each 5 cm stretch.

4. Calculate the work done in each segment and determine the total work done by adding all of the segments together. How does this compare to the work done ~~by~~ *on* the spring calculated in Post-Lab Question 2?

Experiment 2: Conservation of Energy

In this experiment you will explore The Law of Conservation of Energy.

Materials

Masking Tape

1 Ping Pong Ball   *You Must Provide

Tape Measure

*2 Sports Balls (Basketball, golf ball, etc.)

Procedure

1. Find a room with a hard, flat surface that you will be able to drop a ball on.

    Hint: The harder the surface the better.

2. Using the tape measure, measure 0.50 meters above the flat surface. Use masking tape to secure the tape measure to the wall so you will be able to read the height of the ball.

3. Take the ping pong ball and place the bottom of the ball at the 0.50 meter mark.

4. Drop the ball and record the height the bottom of the ball reaches after one bounce in Table 2.

5. Repeat Steps 3 - 4 two more times for the ping pong ball.

6. Repeat Steps 3 - 5 for two other balls of your choice.

Conservation of Energy

Goal:

To disprove or verify conservation of energy using a spring-mass system.

You need:

S-hook with which to suspend spring
Spring
Masses (50, 100, 250, 500) g
Meterstick
Stopwatch (e.g. smartphone or internet)
Video (e.g. smartphone)

Major steps:

1. Determine the spring constant of your spring using the second sheet in this workbook and the various masses.
2. Record a video of the spring's oscillations when the 500-g mass is attached. Make sure that position and time information is evident in the video.
3. Use the third sheet in this workbook to calculate and plot kinetic energy, gravitational potential energy, spring potential energy, and the total mechanical energy.
4. Based on your data, decide whether or not energy is conserved for a mass-spring system.

On this sheet, you will determine the spring constant, k, of your spring

Position of fixed end [cm]:

Position of unstretched free end [cm]:

Measurement number	Position of stretched free end [cm]	Mass [g]	|Force| [N]	Extension [m]
1		50		
2		100		
3		150		
4		250		
5		300		
6		350		
7		500		

Force as a function of extension of spring

Instructions:

1 Hold the meterstick vertically. Determine a position at which you will hold the fixed end of the spring throughout the experiment. Measure the position of the opposite end of the spring to determine its unextended length. Insert the values in Cells B4 and B5.

2 Use the masses to extend the spring and measure the position of the free end for the mass combinations shown. Sometimes you will have to put two masses on the end.

3 Use Excel to calculate the magnitude of the force on the spring and its extension. Your data should be in Cells D7:E13.

4 Choose an appropriate trendline for your data. Display the equation and its R^2 value.

5 What is the value of the spring constant?

k = [   ] N/m

On this sheet, you will determine if energy is conserved.

Position of fixed end [cm]:	
Position of unstretched free end [cm]:	
Equilibrium position of the stretched free end [cm]	
From the previous sheet, your value for k [N/m] =	0

Position number	Position [cm]	Extension [m]	Inc. Position [cm]	Time [s]	Velocity [m/s]	Kinetic Energy [J]	Gravitational Potential [J]	Spring Potential [J]	Total Energy [J]
1									
2									
3									
4									
5									

Conservation of Energy?

Energy [J] axis: 0.000, 0.200, 0.400, 0.600, 0.800, 1.000, 1.200
Right axis: 0.00, 0.20, 0.40, 0.60, 0.80, 1.00, 1.20
Position axis: 0, 1, 2, 3, 4, 5, 6

Instructions:

1 Hold the meterstick vertically. Determine a position at which you will hold the fixed end of the spring throughout the experiment. Measure the position of the opposite end of the spring to determine its unextended length. Insert the values in Cells B4 and B5.

2 Place the 500-g mass on the end of the spring. Measure its equilibrium position. Insert the value into Cell B6.

3 Prepare to take a video of the spring while it is oscillating. Turn on a stopwatch (e.g. internet). Pull the mass straight down 5-10 cm from its equilibrium position and gently release it. While one student holds the spring and the meterstick, the other student uses a smartphone to take a video of a few oscillations, with the meterstick and stopwatch in view.

4 From the video, choose five positions of the free end of the spring during an oscillation. They should be at the top, upper-middle, middle, lower-middle, and bottom of the oscillation. These will be called Positions 1-5.   Write the positions in Cells B9, B12, B15, B18, and B21.

5 Around each Position, increment the video backwards and forwards slightly. Record the Incremented Positions in the white cells between D8 and D22. Record the time corresponding to the Incremented Positions in the white cells between E8 and E22.

6 For each of the five positions, you are to program Excel to calculate the spring's extension (from its unstretched position) and velocity. Pay attention to the units. Enter the values into the appropriate white cells in Columns C and F. For two of the positions, the velocities should be exactly zero, and you may enter zero into the appropriate cells. Likewise, you are to program Excel to calculate the kinetic, gravitational potential, spring potential, and total energies. They are to be entered into the appropriate white cells in columns G, H, I, and J.

7 If you have placed your calculated values in the correct cells, the energies should appear in the plot. Two of the energies should be negative, and their y-values will appear on the right-hand axis. Individually comment in this box if you think energy is conserved for your experiment:

PH 111X C17, Worksheet 8 on the impulse-momentum theorem.

Your name :

- Choose a ball from the bucket. Measure its mass using a mass balance and record the mass in the table.

- Drop the ball from one meter above the floor. Make a video of how high it bounces. Write in the table the initial height (h_i) and the final height (h_f) (that is, the maximum heights before and after one bounce).

- Based on your knowledge of free fall, calculate the ball's velocity immediately before (v_i) and after (v_f) the collision with the floor. Assume a coordinate system with the positive y-direction up.

- Calculate the impulse (**J**) that the ball received from the floor. Assuming a collision time of 5.00 ms, also calculate the average force (**F**$_{av}$) of the collision. Additionally, calculate the ball's change in kinetic energy (ΔK) because of the collision. Write your numbers into the table.

- Repeat the above steps for the two other types of balls. Check that you have indicated the units that you used in the square brackets at the top of each column.

- Individually answer the questions below.

- Submit a PDF of your worksheet at our Canvas site before midnight on Wednesday.

Measurement	Type of ball	Mass [ ]	h_i [ ]	h_f [ ]	v_i [ ]	v_f [ ]	J [ ]	Δt [ ]	**F**_av [ ]	ΔK [ ]
1										
2										
3										

1. Underneath each column of data that corresponds to a vector, indicate the direction of the vector with an arrow.
2. Should the change in kinetic energy be positive or negative? Why?

Worksheet 9 on momentum conservation in collisions　　　　**Your name:**

1.　Each column of coordinate systems below corresponds to a collision of two marbles, each row to a different physical parameter.
2.　Choose two small marbles and one large one. At some point, use a mass balance to determine their masses.
3.　Place one small marble at rest at the origin of the large coordinate system, then roll the other small one towards it along an axis.
4.　Sketch the velocities **v** of the marbles before and after the collision in the appropriate coordinate system below. You need not scale the axes, but make sure that the magnitudes of your vectors are in proportion.
5.　Taking into account the masses of the marbles (if necessary), sketch the momenta **p**. Then rearrange them to show Δ**p** in the coordinate systems of the same column. Ensure that your vectors are in proportion.
6.　Repeat Steps 3-5 for the large marble colliding with a small one at rest, then the small one with the large one at rest.
7.　Individually answer the questions below.

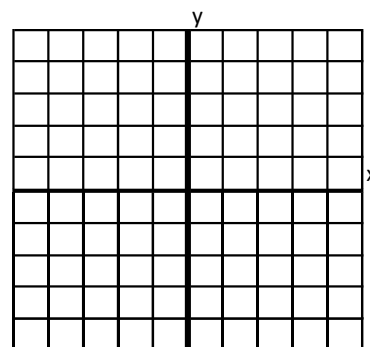mass small marble 1 =　　　　　　　　mass of large marble =　　　　　　　m_large/av_small =
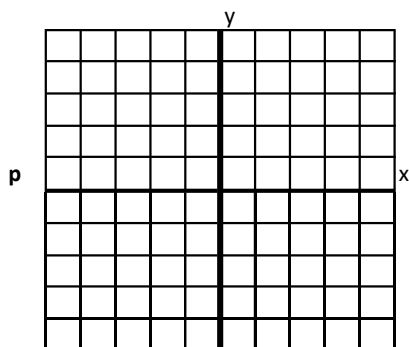
mass small marble 2 =

average mass of small marbles =

Small on small	**Large on small**	**Small on large**

v

p

Δp
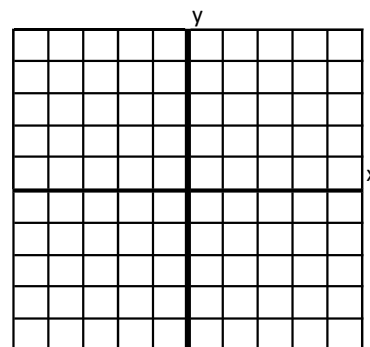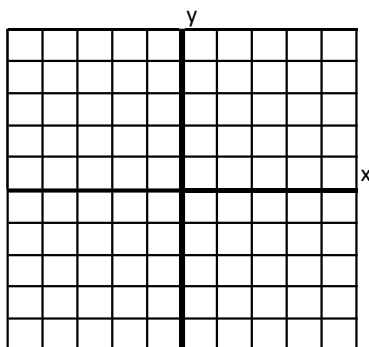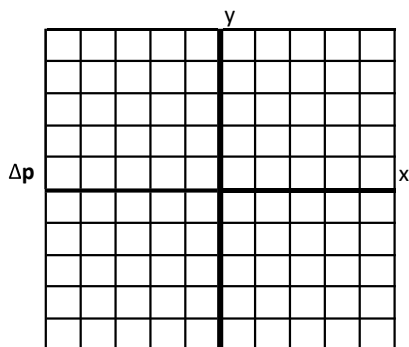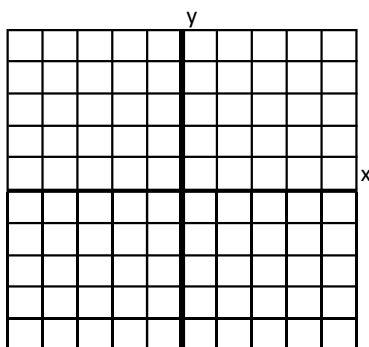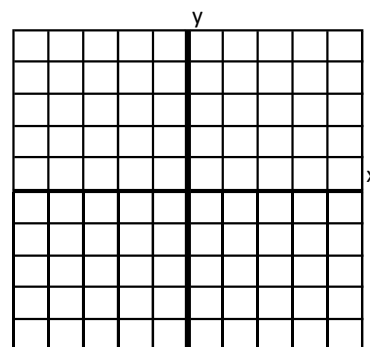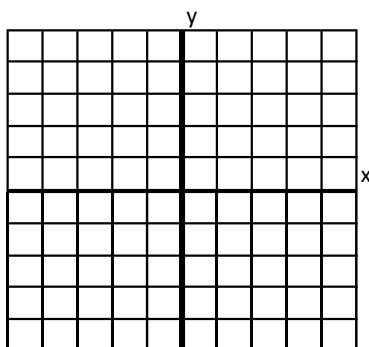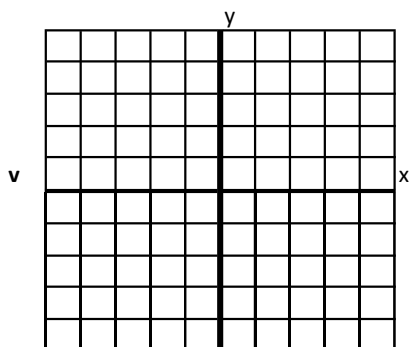
Do your sketches show that momentum is conserved during collisions? Why or why not? Do you expect that kinetic energy is conserved? Why or why not?

Lab 11   Torque and Static Equilibrium

Experiment 3: Torque and Static Levers

In this experiment, you will investigate levers from the perspective of torque.

※ Materials

Mass Set	*Internet*
Masking Tape	*Pen or Pencil
10 N Spring Scale	
Wooden Ruler	*You Must Provide
Computer	

Procedure

1. Place a pencil on a surface such as a table top or counter top parallel to the edge of the counter, near the edge. The pencil will act as a fulcrum (point of rotation).

2. Rest a wooden ruler on the pencil so that the ruler is perpendicular to the pencil. The 0 cm mark should be nearest you and the edge of the surface.

3. Place the 250 g mass on the end of the ruler with its center at the 30 cm mark. To keep the mass stable, use a piece of masking tape to secure the bottom of the mass to the ruler (Figure 8).
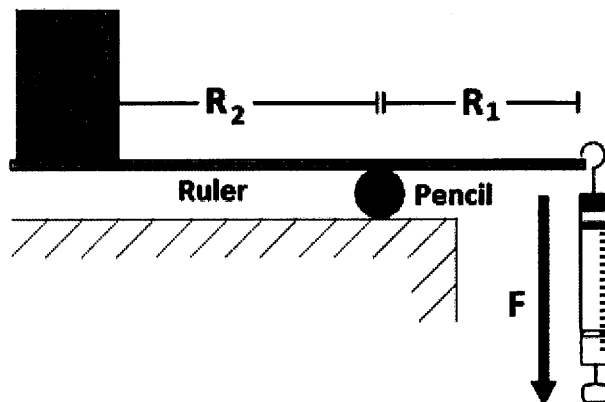

Figure 8: Step 3 reference.

4. Set the fulcrum by sliding the ruler until the pencil is positioned under the 15 cm mark.

5. The distance between the 250 g mass and the fulcrum is the R_2 distance reference in Figure 8. Record the R_2 distance in Table 4.

6. Attach the hooked end of the 10 N spring scale to the end of the ruler that extends off the surface simply by hooking it on the ruler with the end of the hook in the center groove of the ruler. The force scale should be visible to you.

7. Set the hook at the 10 cm mark on the ruler.

8. Record the R_1 distance (between the fulcrum and applied force) in Table 4 as 5 cm (15 cm – 10 cm).

9. Use one hand to secure the pencil and use your other hand to pull down on the spring scale gently until the mass lifts off the table and reaches static equilibrium (ruler parallel to the surface). Record the force (F_1) on the spring scale in Table 4.

> **LAB SAFETY**: Pulling the spring scale down will cause the mass to rise off the table. Using too much force too quickly may cause the mass and/or ruler to catapult towards you. Use caution and wear safety glasses.) We'll provide them if you ask.

10. Shift the hook 1 cm closer to you on the ruler so that it is resting at the 9 cm mark. Record the R_1 distance.

11. Repeat Step 9 –10 for six additional and different R_1 distances.

Table 4: Force Applied at Varying Distances on a Lever				
R_2 Distance (m):				
R_1 (m)	**F_1 (N)**	**T (mN)**	**F_1 (N) Theoretical**	**Percent Error (%)**

Post-Lab Questions , to be answered individually

1. How did the required force change as R_1 changed?

2. Determine the applied torque at each distance. Record the applied torque in Table 4. $(T) = R_1 F_1$

3. ~~Use your answer from Pre-Lab Question 3 to~~ Calculate the theoretical force applied at each R_1 distance. Record the theoretical force in Table 4.

$$\vec{R_2} \times m\vec{g} = \vec{T} = \sum \vec{R_1} \times \vec{F_1} \quad \therefore \left| \vec{F_{1\,theory}} \right| = \frac{m g\, R_2}{R_1}$$

4. Calculate the percent error between the theoretical force and the actual force applied to the lever at each R_1 distance. Record the percent error values in Table 4.

5. How did torque change as the R_1 distance changed? Use your results to support your answer.

6. Create a plot of the force F_1 vs. R_1. Draw a line of best fit through your data. Comment on the relationship between F_1 and R_1. Use your graph to support your answer. Construct your plot on ~~a computer program~~ the provided graph paper on the back of this page. ~~such as Microsoft Excel®. If you do not have a graphing program installed on your computer, you can ac-~~ ~~cess one on the internet via the following links. http://nces.ed.gov/nceskids/createagraph/ or http://~~ ~~www.onlinecharttool.com/graph?selected_graph=bar.~~

7. How would you expect your data to change with an R_2 value half of what you used above?

The purpose of this lab exercise is for you to become familiar with the variables and equations of rotational kinematics. The equations are:

$$\omega_z(t) = \omega_{0z} + \alpha_z t, \qquad \theta_z(t) = \theta_0 + \omega_{0z}t + (½)\alpha_z t^2, \qquad \omega_z^2 = \omega_{0z}^2 + 2\alpha_z(\Theta_z - \Theta_{0z}).$$

1. Write down the angular positions Θ_z that were demonstrated, with appropriate units.

2. Write down the angular displacements $\Theta_z - \Theta_{0z}$ that were demonstrated, with appropriate units.

3. Write down the angular velocities ω_z that were demonstrated, with appropriate units.

4. For the wheel, string, and mass with constant angular acceleration α_z, take a video of the spinning wheel with the stopwatch running in the background. The inner wheel, around which the string is wrapped, has a diameter of 7.5 cm. Don't forget units! What were:

    a. The angular displacement?

    b. The elapsed time?

    c. The angular acceleration?

    d. If the wheel started from rest, what was the angular velocity at the end of the run?

    e. Assuming that the string did not slip or stretch, how far did the mass descend?

5. Repeat Question 4 for the second run with the wheel, string, and mass.

    a. The angular displacement?

    b. The elapsed time?

    c. The angular acceleration?

    d. If the wheel started from rest, what was the angular velocity at the end of the run?

    e. Assuming that the string did not slip or stretch, how far did the mass descend?

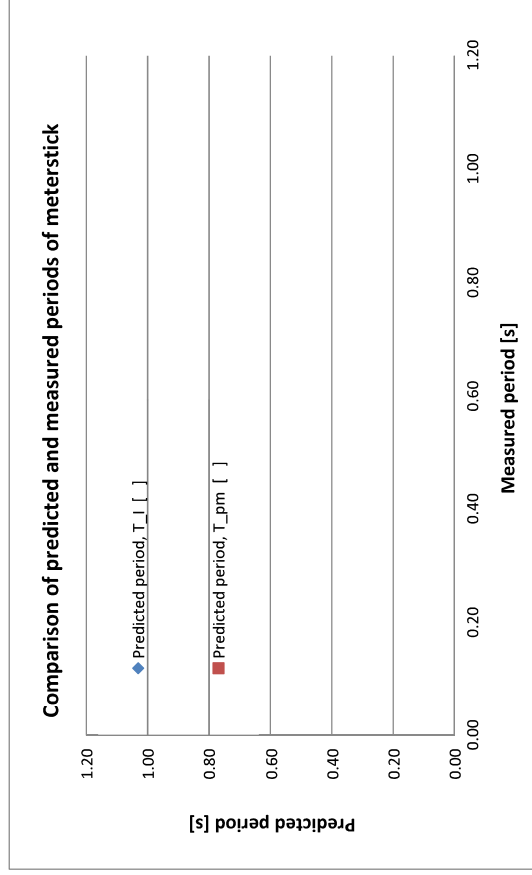**Worksheet 12 on moment of inertia**   **Your name:**

Equipment: Clamp, wooden dowel, meterstick with holes, stopwatch, mass balance

1. At some point, find the mass of your meterstick using a mass balance. Enter the value into Cell B16.
2. Using the clamp and wooden dowel, suspend the meterstick from one of the holes in the range between 25 and 45 cm.
3. The distance d is the distance between the hole and the center of mass of the meterstick. Enter the value into the table.
4. Pull the meterstick to one side by no more than 30°, release it, and time several oscillations. Enter the measured period into the table.
5. Repeat Steps 2–4 for the other four holes.
6. In the appropriate columns of the table, calculate the moment of inertia I, and the predicted periods based on I and the point-mass assumption.
7. In the plot, add an appropriate trendline to the data set that shows the better correspondence between theory and experiment.
8. Display the equation and R^2 value of the trendline.   Also don't forget to indicate units into all of the square brackets.
9. Individually answer the question below. Submit your worksheet to Canvas before midnight on Wednesday.

m [ ] =
g [   ] =   9.80
Pi =   3.14159

Measurement	d [ ]	Moment of inertia, I [ ]	Predicted period, T_I [ ]	Predicted period, T_pm [ ]	Measured period, T_m [ ]
1					
2					
3					
4					
5					

Individually comment on how plotting the measured values on one axis and predicted values based on two different hypotheses on the other axis helps you decide which hypothesis is correct.

Comparison of predicted and measured periods of meterstick

◆ Predicted period, T_I [ ]

■ Predicted period, T_pm [ ]

Predicted period [s]

1.20
1.00
0.80
0.60
0.40
0.20
0.00

Measured period [s]

0.00   0.20   0.40   0.60   0.80   1.00   1.20

Equipment: yo-yo, mass balance, calipers, meter-stick, stopwatch, slow-motion video.

In this lab exercise, you will predict the translational and angular accelerations of a yo-yo as it descends on its string because of gravity.   Then you will compare them to the values that you will measure using slow-motion video on your smartphone. If you do not have a slow-motion option, use the video that is posted at Canvas. Fill in this table and answer the individual questions below. Note that:

1. The inner and outer radii correspond to the spindle and the yo-yo. Measure the inner radius with calipers, once with and once without the string wrapped around the spindle, and take the average.
2. The equations for moment of inertia and the predicted accelerations are on the board.
3. Take slow-motion video of Δy, Δt_y, $\Delta\theta$, and Δt_θ as the yo-yo descends, with a meter-stick and stopwatch in the background. Use kinematic equations to find the measured accelerations.
4. It's likely that your yo-yo will be spinning so fast at the bottom of its run that you will not be able to see the rotations, even with slow-motion video. If so, then use angular displacement $\Delta\theta$ and time Δt_θ values for the first five or ten revolutions. Make sure to report your values with units.

Yo-Yo properties	Predictions
Mass m = Inner radius r = Outer radius R = Moment of inertia I =	Translational a_p = Angular α_p =
Measured translational variables	**Measured angular variables**
Δy = Δt_y = a_m =	$\Delta\theta$ = Δt_θ = α_m =
Percent error	**Ratios**
% error a = % error α =	a_p/α_p = a_m/α_m =

Questions to be answered individually:

1. You might not be able to measure your yo-yo's angular speed ω at the bottom of its run, but you can estimate it from the equations for rotational kinematics and your measured variables. How fast was it spinning just before it reached the end of the string, in both rad/s and rev/s?

2. What should the ratios a_p/α_p and a_m/α_m be equal to? Are they close?

3. What should the shapes of y(t) and θ(t) be?   How about v(t) and ω(t)? And a(t) and α(t)?

Appendix C - Mid-Term and Final Course Evaluation Forms

This appendix includes the Mid-Term Feedback form, as well as the quantitative results of the Final Feedback form.

Mid-term feedback form for PH 111X C17, Appendix

Dear Students,

One question on the mid-term feedback form was ambiguous, and I'd like to repeat it in a way that's probably more familiar to you.

The instructor planned that each studio session would incorporate a variety of activities. For **a typical session**, please rate the helpfulness to learning physics of each main type of activity by circling the appropriate ranking.

Mini-lectures

Very helpful   Helpful   Neither helpful nor unhelpful   Unhelpful   Very unhelpful

Clicker questions

Very helpful   Helpful   Neither helpful nor unhelpful   Unhelpful   Very unhelpful

Lab activities

Very helpful   Helpful   Neither helpful nor unhelpful   Unhelpful   Very unhelpful

Challenging problems solved by instructor

Very helpful   Helpful   Neither helpful nor unhelpful   Unhelpful   Very unhelpful

Problem-solving in groups on whiteboards

Very helpful   Helpful   Neither helpful nor unhelpful   Unhelpful   Very unhelpful

Do you have any comments specific to today's activities?

Most important:

Most helpful:
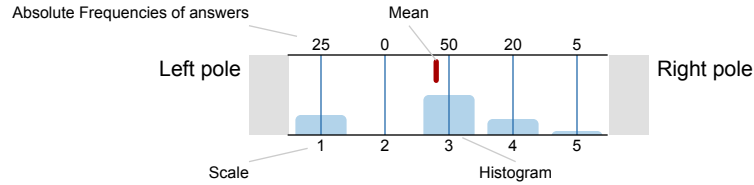
Least helpful:

Prof. Nancy Burnham

PH 111X - C01 STUDIO PHYSICS-MECHANICS (201702_C)
No. of responses = 21

WPI

Survey Results

Legend

Absolute Frequencies of answers — Mean

Question text

| 25 | 0 | 50 | 20 | 5 |

Left pole — Right pole
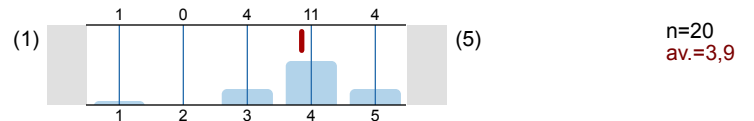
Scale: 1 2 3 4 5 — Histogram

n=No. of responses
av.=Mean
ab.=Abstention

You can help improve the quality of teaching at WPI by providing your responses on this form. Please consider each reply thoughtfully. These reports are used by the instructor for self-improvement, by students during course selection and by members of the administration and faculty committees. Your responses are anonymous and optional. Your comments will not be returned to your instructor until after the grading deadline.
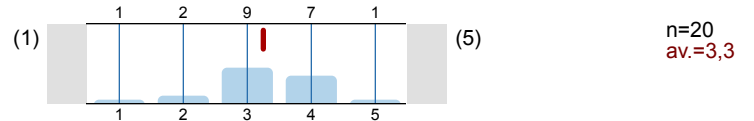

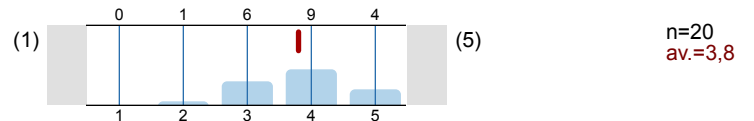**1. My overall rating of the quality of this course is**

Very Poor (1) — (5) Excellent

Frequencies: 0, 1, 3, 11, 6 (scale 1–5)

n=21
av.=4

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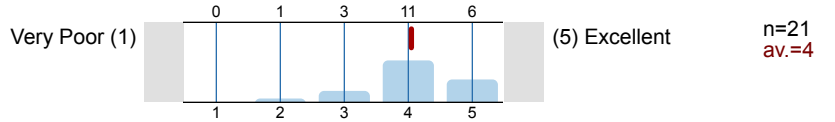
2. My overall rating of the instructor's teaching is

(1) — (5)

Frequencies: 1, 0, 4, 11, 4 (scale 1–5)

n=20
av.=3,9

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3. The educational value of the textbook and/or assigned reading was

(1) — (5)

Frequencies: 1, 2, 9, 7, 1 (scale 1–5)

n=20
av.=3,3

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4. The educational value of the assigned work was

(1) — (5)

Frequencies: 0, 1, 6, 9, 4 (scale 1–5)

n=20
av.=3,8

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5. The instructor's organization of the course was

(1) — (5)

Frequencies: 0, 2, 5, 5, 9 (scale 1–5)

n=21
av.=4

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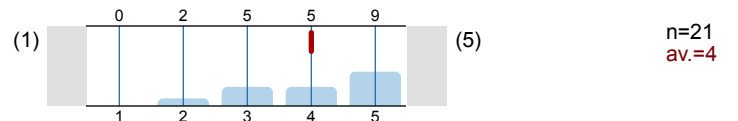
6. The instructor's clarity in communicating course objectives was

(1) — (5)

Frequencies: 0, 2, 1, 9, 9 (scale 1–5)

n=21
av.=4,2

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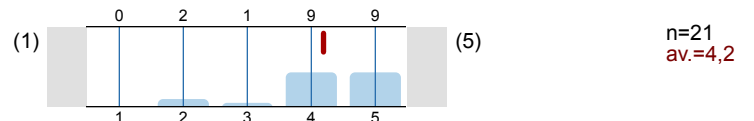
7. The instructor's skill in providing understandable explanations was

(1) — (5)

Frequencies: 1, 0, 5, 7, 8 (scale 1–5)

n=21
av.=4

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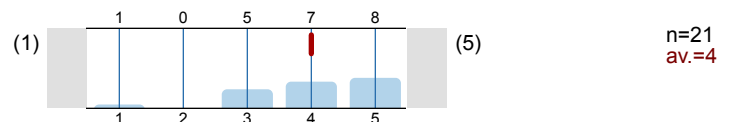
8. The instructor's skill in speaking clearly and audibly was

(1) — (5)

Frequencies: 0, 0, 0, 6, 14 (scale 1–5)

n=20
av.=4,7
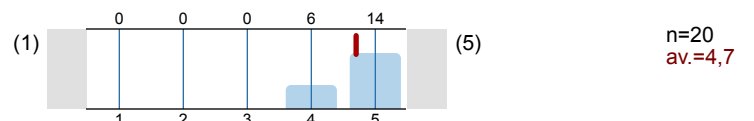
Relative to other college courses I have taken:

9. The amount I learned from the course was

Much less (1) — (5) Much more

Counts: 1, 0, 9, 7, 4

n=21
av.=3,6

10. The intellectual challenge presented by the course was

(1) — (5)

Counts: 1, 1, 2, 12, 5

n=21
av.=3,9

11. The instructor's personal interest in helping students learn was

(1) — (5)

Counts: 0, 1, 5, 9, 6

n=21
av.=4

12. The instructor stimulated my interest in the subject matter

(1) — (5)

Counts: 2, 2, 8, 7, 1

n=20
av.=3,2

13. The instructor encouraged communication outside of regular contact hours

(1) — (5)

Counts: 1, 2, 6, 7, 5

n=21
av.=3,6

14. The amount of reading, homework, and other assigned work was

(1) — (5)

Counts: 0, 1, 3, 8, 9

n=21
av.=4,2

15. My attendance and participation for this course was

(1) — (5)

Counts: 0, 1, 2, 7, 11

n=21
av.=4,3

16. The amount of effort I put into this course was

(1) — (5)

Counts: 0, 1, 2, 9, 9

n=21
av.=4,2

How frequently were the following statements true in this course?

17. The instructor was well prepared to teach class.

Never (1) — (5) Always

Counts: 0, 0, 1, 7, 13

n=21
av.=4,6

18. My instructor used course time effectively.

(1) — (5)

Counts: 0, 0, 6, 7, 8

n=21
av.=4,1

19. The instructor encouraged students to ask questions.

(1) — (5)

Counts: 0, 1, 2, 10, 8

n=21
av.=4,2
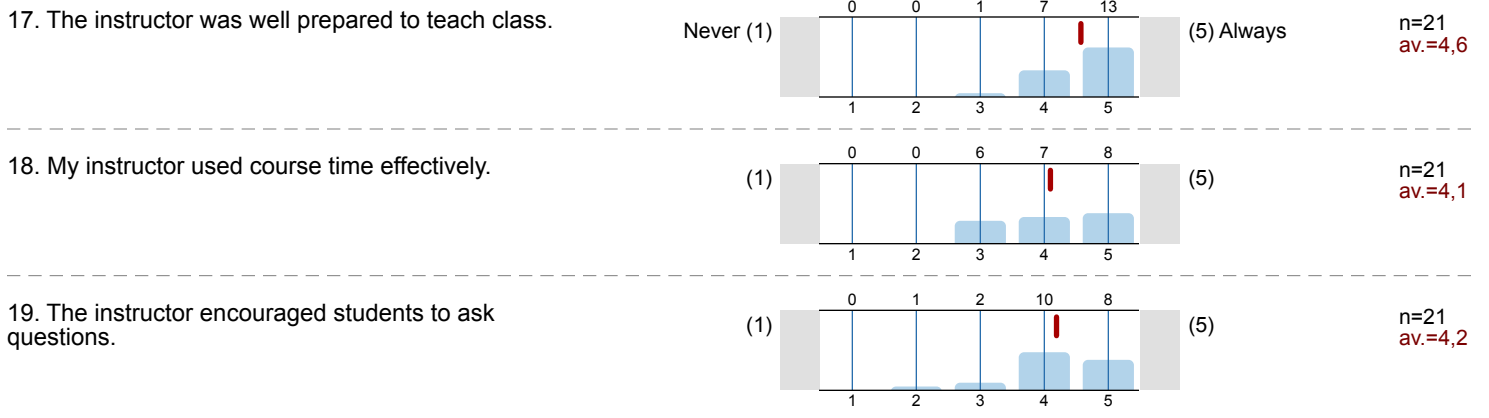
20. The instructor treated students with respect.

(1)   (5)

	1	2	3	4	5
	0	0	3	3	15
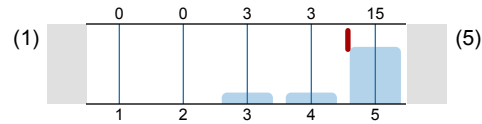
n=21
av.=4,6

21. Instructor feedback on exams/assignments was timely and helpful.

(1)   (5)

	1	2	3	4	5
	0	1	8	5	7
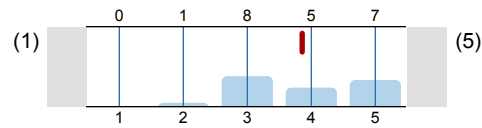
n=21
av.=3,9

22. The exams and/or evaluations were good measures of the material covered.

(1)   (5)

	1	2	3	4	5
	3	2	3	5	8
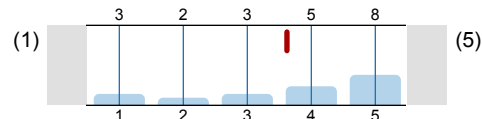
n=21
av.=3,6

23. My grades were determined in a fair and impartial manner.

(1)   (5)

	1	2	3	4	5
	0	1	3	10	7
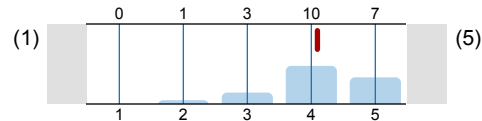
n=21
av.=4,1

24. What grade do you think you will receive in this course?

n=21

A	5
B	7
C	4
NR/D/F	2
Other/Don't know	3
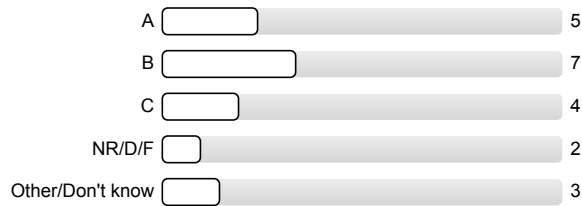
25. Which of the following best describes the role of this course in your academic program?

n=21

In your major field	2
Required for major	16
Free elective	0
Required for minor	1
Other Requirement	2
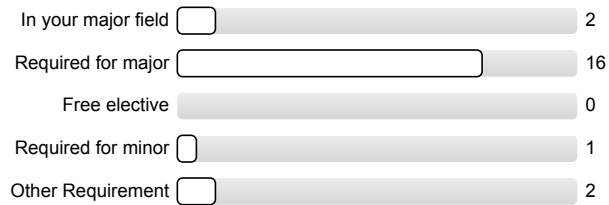
**26A. On average, how many hours of the formally scheduled hours for lecture, conference, and labs did you ATTEND each week?**

n=20

|	
3 hr/wk or less	0
4 hr/wk	0
5 hr/wk	17
6 hr/wk	2
7 hr/wk or more	1
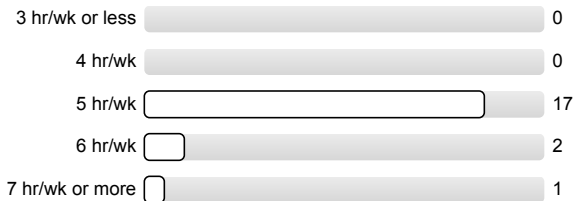
26B. On average, what were the total hours spent in each 7-day week OUTSIDE of formally scheduled class time in work related to this course (including studying, reading, writing, homework, rehearsal, etc.)?
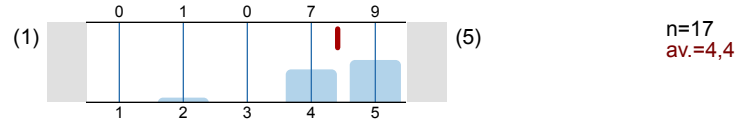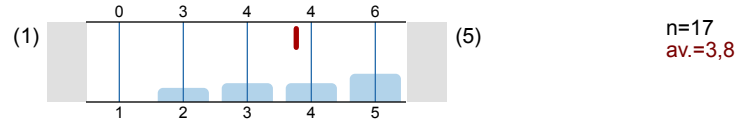
n=21
av.=4

0 hr/wk	0
1-5 hr/wk	1
6-10 hr/wk	10
11-15 hr/wk	4
16-20 hr/wk	1
21 hr/wk or more	5
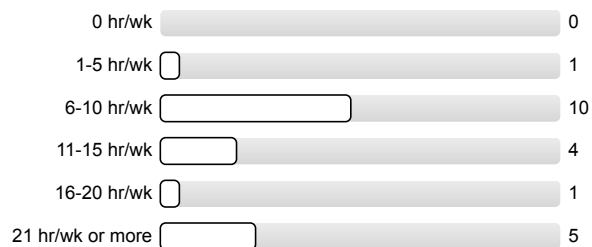
For courses with laboratories only:

27. The instructor showed me how to use lab equipment properly.

Never (1) — (5) Always

n=17
av.=4
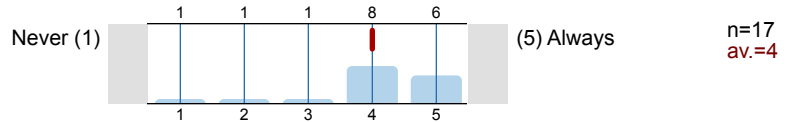
28. The lab and/or computer equipment was in good operating condition.

(1) — (5)

n=17
av.=4,4

29. Good laboratory procedures were emphasized

(1) — (5)

n=17
av.=3,8

30. Relative to other lab experiences, the intellectual challenge presented by the lab assignments was

Much less (1) — (5) Much more

n=17
av.=3,7
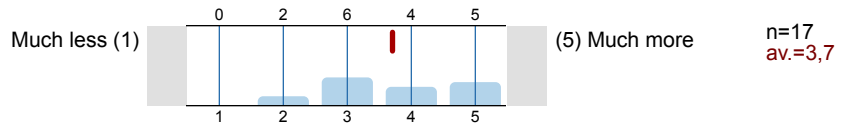
31. Relative to other lab experiences, the clarity and specificity of lab assignment objectives was

Much less (1) — (5) Much more

n=17
av.=2,9
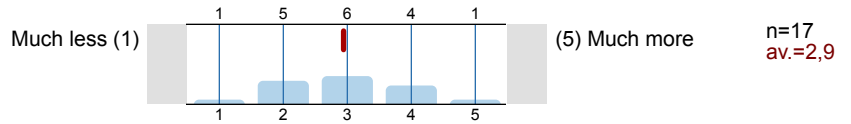
Please use the following to answer additional question(s) that may be provided by your instructor:

Instructor provided ranked question #1

Low rating (1) — (5) High rating

n=2
av.=4,5
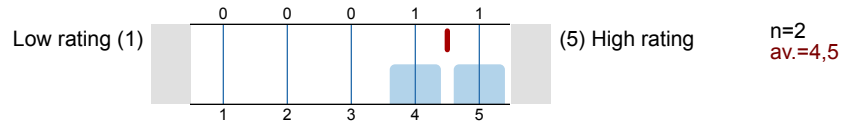
Instructor provided ranked question #2 — The evaluation will not be displayed due to low response rate.

Instructor provided ranked question #3 — The evaluation will not be displayed due to low response rate.

Instructor provided ranked question #4 — The evaluation will not be displayed due to low response rate.

Instructor provided ranked question #5 — The evaluation will not be displayed due to low response rate.

Instructor provided ranked question #6 — The evaluation will not be displayed due to low response rate.

Instructor provided ranked question #7 — The evaluation will not be displayed due to low response rate.

Instructor provided ranked question #8 — The evaluation will not be displayed due to low response rate.