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REAL TIME PHYSICS IMPLEMENTATION IN PH1110

An Interactive Qualifying Project Report

submitted to the Faculty

of the

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1. **Education**
2. **Laboratory**
3. **Physics**
4. **Real Time Physics**

Table of Contents

Table of Contents 2
Abstract 4
1 Introduction 5
2 Background 7
2.1 Cause of difficulties with physics 7
2.1.1 General education difficulties 7
2.1.2 Specific problems in physics education 8
2.2 Understanding common misconceptions in physics 9
2.3 The traditional physics course 12
2.4 The non-traditional physics course 12
2.5 The five current traditional labs 13
2.5.1 Lab 1 "The Vector Nature of Force Part 1" 13
2.5.2 Lab 2 "The Vector Nature of Force Part 2" 13
2.5.3 Lab 3 "The Spring Force" 13
2.5.4 Lab 4 "Torque" 14
2.5.5 Lab 5 "Equilibrium of an Unconstrained Extended Object" 14
2.5.6 Traditional lab experience 15
2.6.1 Real Time Physics 15
3 The Project 17
3.1 Project Objectives 17
3.2 Experimental approach 18
4 Procedure 20
4.1 Overview 20
4.2 Creating the active learning labs 20
4.3 The Real Time Physics labs 21
4.3.1 Lab 1: Constant Velocity Motion 22
4.3.1 Lab 2: Constant Velocity Motion 23
4.3.3 Lab 3: Force and Motion 24
4.3.4 Lab 4: Collisions 24
4.3.5 Lab 5: Collisions Part 2 25
4.3.6 Other considerations 25
4.4 Implementation of the five active learning labs 26
4.4.1 Equipment list 26
4.4.2 Setting up the lab 27
4.4.3 Permissions 27
4.4.4 Data Collection for Real Time Physics Labs 27
4.5 Control and experimental groups 28
4.5.1 Tutorial Experimental Group 28
4.5.2 Tutorial Control Group 29
4.5.3 One-hour Experimental Group 29
4.5.4 One-Hour Control Group 30
4.6 Methods of Analysis and Assessment 30
4.6.1 Exam and Course Grades 30

4.6.2 Pre And Post FCI Data Sample Selection 31
4.6.3 Breakdown of the FCI Questions Into Conceptual Topic Groups 32
4.6.4 F test 33
4.6.5 D test 33
4.6.6 ϕ test 34
4.6.7 Alternative Test: Estimation Via The Standard Deviation 35
4.6.8 Analyzing Students' Attitudes Via Surveys 35
5 Results and Analysis 36
5.1 Overview Of FCI Gains By Experimental Group 36
5.1.1 Post-Test Gain (g) Comparison 36
5.1.1.1 One-hour Post-Test Gain Vs. One-hour Control 36
Table 5.1: FCI Test Score Gain Comparison For 1HR and Its Control Group 37
5.1.1.2 Tutorial Post-Test Gain Vs. Tutorial Control Post-Test Gain 38
Table 5.2: FCI Test Score Gain Comparison For Tutorial Its Control Group 39
5.1.2 Normalized Learning Gain <g> Comparison 39
5.1.2.1 One-Hour <g> Vs. One-Hour Control <g> 39
5.2.1.2 Tutorial <g> Vs. Tutorial Control <g> 41
5.1.3 Summary Of FCI Post-Test and Normalized Gains 41
5.2 Break Down of FCI Gains by Physics Topic 43
5.2.1 Data Analysis 43
5.2.2 One-Hour group 43
5.3 FCI Gain Analysis By Grade 46
5.3.1 Data Analysis 46
5.3.2 One-Hour Experimental Exam Group vs. Its Respective Control Group 47
5.3.3 All One-Hour Exam Groups vs. All The One-Hour Control Groups 48
5.3.4 Summary of FCI Analysis By Grade 50
5.4 Analysis of Surveys 50
5.4.1 Student Attitudes 50
5.4.2 Summary of Student Attitude Analysis 54
6. Conclusions 56
7. Authorship 59
8. Acknowledgements 60
9. List of Works Cited 61
Appendix I: Modified RTP labs 62
Lab 1: Constant Velocity Motion 62
Lab 2: Motion with Changing Velocity 70
Lab 3: Force and Motion 77
Lab 4: Collisions 84
Lab 5: Collisions Part II 90
Appendix II: Letter For Copyright Permission 97
Appendix III: Student Attitude Survey 99

Abstract

This project was an investigation and implementation of a new technological innovation in physics education. It employed modified Real Time Physics labs to convert the current physics labs in use by WPI into computer-assisted active-learning labs. The effectiveness of the new labs was measured by exam grades, surveys of students' attitudes, and pre and post-instruction administration of the Force Concept Inventory (FCI) test, which tests the students' conceptual understanding of physics. Survey results indicated that the students enjoyed the labs and that they believed they learned from them. Statistically significant increase in the grades and the physics conceptual learning gain could be achieved only if the experiment were redone with more students or using a conceptual test other then the FCI.

1 Introduction

Physics is at the root of most science and engineering professions as well as being important to everyday life and yet, despite this, an understanding of physics has remained an elusive goal for most students. Physics is generally considered by most college freshmen to be the most difficult course in their first year. It is this underlying difficulty that has led to a lack of understanding of physics, which has now, unfortunately, become a part of our society. The degree to which an understanding of physics is lacking in our society threatens the very infrastructure of intellectual advancement by hindering the heights to which scientists, technicians, inventors, and innovators can reach in their respective fields because it is at these great heights that physics is a crucial component. This lack of understanding of physics leads to a never-ending cycle in which students enter a physics course with some inherent problems with physics concepts and afterwards they develop an apprehension about physics. This has continued for a few generations and has led to the current state in which one is almost expected to dislike physics. The root of the problem is with the physics misconceptions that most students seem to have before they enter college. The current state of physics education research is to understand this inherent problem with physics concepts and then figure out ways to remove these problems and difficulties so that the student can finally successfully learn physics.

There has been quite a bit of research in the area of physics education, and there are thus many new and innovative techniques of teaching physics. The difficulty with employing many of these new techniques is that either a lot of teacher training or expensive technology is needed. Neither of those difficulties can be avoided; one can only attempt to minimize the difficulties associated with the implementation of new teaching techniques.

The motivation behind this project is that many WPI Physics professors feel that the current labs do a poor job in teaching students the concepts behind physics. Real Time Physics is a better way to give students hands-on experience with physics. The proposed labs also take advantage of new technology that the current labs lack. This project attempted to introduce the use of computers into the introductory non-majors physics course in mechanics at WPI by modifying the current lab experiments with active learning lab experiments (Real Time Physics). We attempted to minimize cost and teacher training while replacing the labs. The first goal of the project was to create one-hour modified versions of the published two-hour Real Time Physics labs to replace the current traditional one-hour labs. (Using unmodified Real Time Physics labs would have been more difficult without changing the infrastructure of the course.) The effectiveness of the modified Real Time Physics labs in an actual introductory physics course was measured by a concept test administered before and after instruction. The data collected from the initial implementation of the modified Real Time Physics labs can be used to further modify the labs. It is the hope of the authors that all 5 active learning labs will eventually be used for the entire PH1110 and PH1111 classes.

2 Background

2.1 Cause of difficulties with physics

Difficulties with physics arise from general problems in education and more specific problems in physics education.

2.1.1 General education difficulties

All areas of education encounter the same difficulties in teaching that physics professors must deal with. The underlying difficulty is that students enter class with misconceptions they acquired through experience and for a student to truly learn the subject in question, the teacher must attempt to not only show the student the correct concepts but also convince the student that his original concepts are in fact misconceptions (Wankat & Oreovicz, 1993). In education the latter condition is rarely fully realized and thus a student will finish the course and not truly understand the material. One type of student will most likely survive the course via strict memorization of the material as opposed to actually understanding the material. When answering a question the student will answer in a way that might satisfy the professor by recalling something memorized or by taking an educated guess, instead of thinking it out and answering to the best of his or her understanding. The distinction can be shown as the difference between a student asking himself or herself "How does the professor want me to answer the question?" instead of "How do I answer the question?". Sadly, a student can appear to be a "good" student by using this method for his or her entire undergraduate career. Another type of student, who usually does well in a course, is the student who comes into the course with the fewest misconceptions, perhaps by being exposed to various aspects of the course material in a proper manner at an earlier time.

2.1.2 Specific problems in physics education

Overcoming a student's misconceptions is a tremendous task for the physics professor. This is because the concepts addressed in physics contradict a student's own conceptions more so than in any other subject. Students develop their own concepts about the physical world via their everyday experiences. Despite the fact that introductory physics deals with the concepts of force and motion in the everyday world, students still have trouble relating to it. The problem stems from an internal conflict between two basic beliefs that students have when taking a physics course. The first belief is that what the professor teaches about the physical world is correct. This is usually reinforced when the student views his or her professor as an authority in physics. The second belief the student has is that everything the student has learned about the world from experience is correct. This belief is in essence a student's own common sense, which the student rarely doubts. When there is a contradiction between the two beliefs, the student will always rely on the second belief, common sense. But when such a contradiction arises it does not mean that either belief is false; rather, it usually means that the student's interpretation of past experiences is incorrect. The student would rather question what the professor is teaching about physics than question his or her own interpretation of his/her own experiences. Unfortunately, traditional physics courses fail to address this internal conflict and the result is that students keep their misconceptions. From this it is apparent that an effective method of physics education would be one that concentrates upon identifying and correcting the student's misconceptions.

2.2 Understanding common misconceptions in physics

Before an educator can explore methods of reconstructing common student misconceptions, an educator must understand what those misconceptions are. Several studies have attempted to identify and understand common misconceptions. It is important to identify not only the type of misconception the student has but also the degree to which that misconception deviates from the correct concept. For example, when a student is asked the question below (Mazur, 1996), odds are that s/he does not know the correct answer.

> A sled moves to the right on a frictionless plane. What force is required to keep it moving at a constant velocity?
>
> A. An increasing force to the right.
> B. A constant force to the right.
> C. A decreasing force to the right.
> D. No applied force.
> E. A decreasing force to the left.
> F. A constant force to the left
> G. An increasing force to the left.

The correct answer is "D" (Thornton, 1998). A correct answer might mean that the student understands that an object can move with a constant velocity without any applied force and that only when the object accelerates is a force being applied. A student with the most common misconception about motion would answer "B", indicating that the student believes that all motion requires a force. This is not as strange as it sounds if you consider that we live in a world that generally does not have frictionless planes. It is because of friction and air resistance that students believe that a force is always needed for motion. Even if students believe that a constant velocity requires a constant force, they still may be able to correctly answer a similar problem in a correct way. For example, a good way to target where they may digress from a correct conceptual framework would be to have a multipart question such as the following (Thornton, 1998):

> Part 1: An astronaut is on the space shuttle orbiting the earth. He gives a ball a small nudge so that it is moving to the other end of the shuttle, 10 meters away, at a constant velocity. Will the ball stop before it hits the other end of the ship? Ignore air resistance.
>
> Part 2: If the shuttle is 100 meters long, will the ball stop before it hits the other end of the shuttle? Ignore air resistance.
>
> Part 3: When the shuttle is 1 kilometer long? Ignore air resistance.

After having actually seen astronauts in space on TV, this almost counts as an everyday experience for most people. Most students would probably answer the first question correctly (NO). In the second or third part, despite the plea to ignore air resistance, the student may still consider air resistance and answer incorrectly with YES. They may not even think that they are considering air resistance. They may just think "all things slow down". Even if students were able to successfully answer all three parts of the space shuttle question, they may still not make the connection to correct concepts and when asked the question about the sled again they would answer incorrectly again. This would probably occur even if the professor spent an entire traditional lecture period on the concept of air resistance and friction. The professor could "tell" the student that his concepts are wrong but even after that the student may still answer the same question incorrectly.

Such persistence of misconceptions has actually been shown with two important tools, the Force and Mass Concept Exam or FMCE (Thornton, 1998) and the Force Concept Inventory or FCI (Hestenes *et al.*, 1992). Both of these tools are multiple choice tests designed specifically to identify and analyze a student's misconceptions in mechanics. Using the FMCE and the FCI, it has been shown on numerous occasions that the level of conceptual understanding of physics after a student has taken an introductory physics course is only slightly better than the level of understanding before he or she entered the course. The degree of difference is almost negligible in certain specific concept areas. Either of these two tests (FMCE and FCI) is more than sufficient to identify and understand students' misconceptions. With these tests methods of correcting the misconceptions can now be explored.

2.3 The traditional physics course

A traditional physics course consists of two parts, the lecture and the lab. The lecture concentrates only on attempting to dictate the correct concepts, a method that we know to be flawed (Mazur, 1996). To a student, attending a traditional lecture is often a passive experience. This method of learning is clearly not adequate to motivate the student to reconstruct his or her conceptual infrastructure developed over many years of "active" experiences. In most cases, the lab part of a traditional physics course will only attempt to demonstrate some isolated concept taught in class and does not help the student understand the concept.

2.4 The non-traditional physics course

For physics to be taught effectively it must be done in a way that is similarly active to the process by which a student learned the misconceptions. There are several ways to implement a more active learning style in physics. One method that can be implemented without altering lecture is the use of a feedback system known as ClassTalk (or similarly PRS, Peer Response System) (Mazur, 1996). Active learning labs that incorporate a more active learning style are highly effective and will be the basis of this project. The original Real Time Physics (RTP) curriculum (Sokoloff *et al.*, 1998) is a complete lab course, in which the lecture part of the course can be reduced. In this project, we did not reduce the lecture; instead we attempted to integrate RTP labs into the existing lecture framework.

2.5 The five current traditional labs

The five current PH1110 labs focus on vectors and forces. In general the five labs examine static cases where there is a force acting upon an object but it does not move because there is another opposing force acting upon the object.

2.5.1 Lab 1 "The Vector Nature of Force Part 1"

As the name implies, lab 1 deals with treating forces as vectors. In the lab the student is given an object to which he or she attaches three strings. At the other end of each string hangs a weight over the edge of the table. The weights are chosen and the strings are positioned in such a way as to have the object be stationary. The purpose of the lab is to show, through an exercise in drawing vectors, that the vector sum of the forces is zero. The main concept obtained is that force is a vector and must be treated accordingly.

2.5.2 Lab 2 "The Vector Nature of Force Part 2"

This lab is a continuation of the previous lab. The only difference between this lab and lab 1 is that now the students deal with four forces instead of three. The main objectives and concepts are the same as in the previous lab. This lab allows the students further practice with drawing vector diagrams.

2.5.3 Lab 3 "The Spring Force"

In this lab students hang masses from springs and measure the length of the spring before and after the mass is hung. From this they calculate the spring constant. This is still basically a static case. The main concept in this lab is that springs stretch and the degree to which they stretch is related by F=-Kx (F is the force applied, K is the spring constant, and x is the amount the spring is stretched).

2.5.4 Lab 4 "Torque"

This lab and the next resemble the first two labs. The difference now is that we are dealing with torques instead of forces acting on an object. The object is still stationary, but now the students are concerned with the fact that the object is not rotating. In the setup the students attach four strings to a board-like object that is kept stationary via a pin through the center. To the other end of each string is attached a mass which hangs over the edge of the table. The strings are attached to the board near its end so that the board will experience a torque from the strings. The main concept in this lab is that the board does not rotate because the sum of the torques is zero, just like in lab 1 where the object did not move because the sum of the forces is zero.

2.5.5 Lab 5 "Equilibrium of an Unconstrained Extended Object"

This lab is similar to the lab 4 except that in lab 5 there is no pin through the center of the board keeping the object stationary. The object is free to rotate and to translate but in this lab the board is once again in static equilibrium. Now the main concept is that the board does not move and does not rotate because the sum of the torques and the sum of the forces are both zero.

2.5.6 Traditional lab experience

The traditional labs do not involve any understanding of physics concepts. All of the labs can be done simply by collecting data and running the data through a set of formulas. The students do not have to learn anything from these labs as long as they get good data and their error percent is below x%. Understanding what happens in the lab is useful but not a requirement.

2.6.1 Real Time Physics

Real Time Physics is a lab only course that uses computers to give the student instant feedback with regards to the force and motion experiments. This is done through software that plots in real time data received from force and motion sensors connected to the computer. The students use the probes to study the motion of low friction carts on tracks. The computer and probes allows the student to receive instant feedback in an experiment, allowing the student to truly "experiment" and explore some concept in physics. A student will be able to understand that F=ma by doing a simple experiment with low friction carts or air tracks and seeing the results plotted on a computer screen in real time. The student also makes a prediction beforehand of what s/he thinks the answer will be, and then is asked after the experiment whether what s/he thought would happen actually did. This allows a student to learn in a way that closely mimics his or her real life experiences by allowing for instant and accurate feedback and also through the use of predictions, the student is able to clearly see the difference between his/her misconception and the actual concept. A student who answered the sled question mentioned in section 2.2 incorrectly was given that question after a lab with a low friction cart. After the students analyzed data of the carts velocity and acceleration after a force was applied to it, s/he was able to answer the question correctly.

3 The Project

3.1 Project Objectives

- **Modify Real Time Physics labs to fit into current lab periods.**
- **Implement modified one-hour version of the Real Time Physics labs into the WPI physics PH1110 course in A-term of 2001.**
- **Implement original two-hour version of the Real Time Physics labs into the WPI physics PH1110 course in A-term of 2001.**

The most effect method of implementing active learning in physics at WPI would be to fully incorporate Real Time Physics into the introductory physics course. Restructuring labs for the whole course would be impractical in a short time and it would be difficult to justify expense and rescheduling without a pilot test to convince the Physics Department of its value. Since all the PH1111 (calculus based) and PH1110 (algebra based) sections do the same labs, the greatest impact with the least effort could ultimately result from altering the labs since we would not need to make special labs for one or the other course. In addition, since lab and lecture instruction are separate, one can change the labs without having the professors change their teaching styles. It would be more feasible for the Physics Department to gradually implement an active learning lab over the course of a few years to allow for adjustment. It was the focus of this project to implement active learning labs on a small scale in a way that is as effective as possible but with the least change to the professors' individual styles of teaching. We modified only the lab portion of General Physics-Mechanics (PH1110) in a way that would not require any alteration to the lecture.

3.2 Experimental approach

We modified the lab portion of PH1110 by partially implementing the Real Time physics labs (Thornton, 1998) in a way that fit best into the current course structure. The purpose of the project was to incorporate such labs in a way that effectively balanced the impact on student learning, the class time available, and cost. We needed new equipment (software, probes, interface) in order to execute this successfully. The equipment currently available at WPI was old and the software we had was designed to run on even older computers. The currently available equipment and software is much more precise and user-friendly.

The Real Time Physics labs had to be shortened for use in physics PH1110. Special care had to be taken to retain the effectiveness of the RTP labs. First the RTP labs were modified to replace the current five labs in the PH1110 course. They were changed because the original RTP labs include a pre and post lab sections, which would have been impossible to complete in a 50-minute lab period. In addition, several activities were either cut or shortened from each lab in order to fit the lab into period. The modified labs were then pilot tested on twenty-four randomly selected students enrolled in the PH1110 course. In conjunction with these modified RTP labs we also tested the original two-hour version of each RTP lab with another group of 24 students from the Davis Tutorial group. In each case, the experimental groups were divided into groups of four for purposes of conducting lab experiments. We used the students taking the traditional PH1110 labs as our control group. From this control group we created separate control groups for both the one-hour group and the tutorial group (see section 4.5).

Tests and surveys were administered to assess the effectiveness of the labs in teaching physics concepts. The FCI was administered pre-course and post-course, grade data were collected from the course instructors, and students were administered surveys to obtain their input about the labs.

4 Procedure

4.1 Overview

The project consisted of three parts. The first part, during C & D terms 2001, involved the modification of the active learning labs that were implemented in A-term 2001. The second part, in A-term 2001, involved the implementation of the active learning labs and the collection of data in the PH1110 course. The third part occurred in B-term 2001, after the course had been completed and it involved analyzing the effectiveness of the active learning labs.

4.2 Creating the active learning labs

The active learning labs used were modified from the Real Time physics labs in order to fit within the WPI introductory physics course format. There were five major issues that made a full implementation of the Real Time physics labs impossible without drastic changes. The first major issue was the difficulty with fitting the Real Time physics labs into the current WPI PH1110 curriculum. PH1110 currently offers a half semester of one-hour labs while Real Time Physics requires a full semester of two-hour labs. The Real Time Physics labs were designed for a lab course that would have 12 two-hour labs, whereas the PH1110 has five one-hour labs. Other issues were that the Real Time Physics labs had to be modified in a way that keeps the costs, training, and other concerns in mind while still being effective at teaching physics. The Real Time physics labs were written with pre-labs and post-labs that aid in the understanding of the material. The current labs do not have pre- or post- labs and it is impractical to require more work from the one-hour experimental group than the one-hour control group. The last of the major issues was the fact that the Real Time physics labs follow a sequence of physics topics that differs from the traditional lecture sequence. Since the traditional lecture is to be retained then the new active learning labs have to follow a sequence of topics that correspond to the current lecture. In order to address these issues, the five current labs in the PH1110 course had to be analyzed and compared with the twelve Real Time Physics labs.

4.3 The Real Time Physics labs

The Real Time Physics labs focus on motion (velocity, acceleration) and forces and attempt to teach them conceptually. These labs use motion sensors, force probes, and advanced computer software to allow the students to graph the data instantly on the computer for analysis. This de-emphasizes the calculation and emphasizes the concepts behind them. We altered the Real Time Physics labs so as to reduce their time usage while keeping their effectiveness. The first thing we did was strip out all the pre-labs since we felt that the students had enough preparation on lab topics from lecture and conferences and also because of time constraints. We used the post-labs as the homework assignments for our labs. The post labs are basically questions about the lab but do not require data specifically from the labs, just knowledge of the concepts taught. The post labs are equivalent work to the lab reports done for the traditional labs. There were also lab worksheets (Appendix I) that students completed during the lab session. These worksheets reinforce concepts taught in the lab through calculations. The post labs were graded out of 10 points, and represented 10% of the final grade. The following is a detailed description of the lab objectives (bullets) and how each lab achieves them.

4.3.1 Lab 1: Constant Velocity Motion

- *To learn to use the motion sensor, cart and software*

This lab has the students use the motion sensor to measure the velocities of a low friction cart moving on a track and use the software to display a velocity vs. time graph. This lab is simple because this is be the first time that the students have used this equipment.

- *To learn significant figures*

The students fill out several charts with the proper significant figures. These labs are not the best medium for teaching significant figures because the labs are more concept-based than calculation-based. We included this because the Physics Department required the first lab to teach significant figures.

- *To learn the concept of displacement*

The students move their body in front of the motion sensor in such a way as to copy graphs, and the software creates graphs based on the students' movement. The lab worksheet gives directions for moving (i.e. "move away from the motion sensor at a slow pace"). This allows them to see how the displacement of their own movement in relation to the motion detector alters the graphs.

- *To learn the concept of velocity*

The students use the motion of their bodies, walking quickly and slowly, while graphs are displayed in real time on the software. This allows the students to see in real time how their motion affects the velocity chart and hopefully helps them to understand the concept of velocity.

- *To understand the relationship between displacement and velocity*

When creating the velocity graphs, students also simultaneously create displacement graphs and are asked to analyze the relationship between the two graphs.

4.3.1 Lab 2: Constant Velocity Motion

- *To understand the meaning of acceleration, its magnitude, and its direction*

This is really the focus of the lab. Students use a cart with a pulley and weight and graph its acceleration when the weight, attached to the cart and pulled by gravity, falls to the floor. This simple exercise hopefully teaches the fundamentals. Later the students give the cart a push in the opposite direction so the cart has some initial velocity in the negative direction. This will cause the cart to slow, stop, and speed up going backwards. They see the bell curve shaped graph of displacement and understand how acceleration works depending on its direction (i.e. positive if accelerating away from the detector)

- *To discover the relationship between velocity and acceleration graphs*

In the exercises mentioned above, the students also simultaneously create velocity and acceleration graphs with the software to assist in determining the relationship.

- *To understand how to use vectors to represent velocity and acceleration*

After the students learn that direction is important to acceleration and velocity, they are asked to draw some vectors in relation to the exercises they just completed.

- *To calculate the average acceleration and average velocity*

This is an exercise in learning more about the software that came with the RTP equipment. All they had to do was click a button to calculate this, but in some of the exercises dealing with vectors they would see that the average velocity and acceleration were not what they predicted and the concept would become clearer.

4.3.3 Lab 3: Force and Motion

- *To learn how to use a force probe to measure force*

Students pull and push the force probe while the software records the force.

- *To explore how the motion of an object is related to the forces applied to it*

This lab requires the students to apply several forces to a cart with a force probe attached to it. The force probe measures the forces they apply to it and the cart moves appropriately. The cart's movement is shown on the software through displacement and velocity graphs. This allows the students to see the relationship clearly.

- *To find a mathematical relationship between the force applied to an object and its acceleration*

The students make graphs of force and acceleration and find that the slopes are similar. This helps them to derive F = MA.

4.3.4 Lab 4: Collisions

- *To understand momentum and impulse*

The students calculate the momentum and impulse for household objects and discover the relationship between them.

- *To study the interaction of forces during collisions*

Students measure the force of falling objects hitting the ground. They graph and examine this force and the relation to impulse.

- *To understand elastic and inelastic collisions*

One of the objects dropped is rubber so it bounces back and the other object is clay so it sticks. The students see how each type of object is affected by the force of the ground on the object.

4.3.5 Lab 5: Collisions Part 2

- *To understand Newton's 3rd law as applied to collisions*

The students cause two carts to collide and measure the force of each cart on the other. They find that the two forces are equal and opposite to each other.

- *To understand the law of conservation of momentum*

They calculate the total momentum before and after the collision to find that they are the same.

- *To explore conservation of momentum*

Through several exercises involving collisions, the students explore the conservation of momentum.

4.3.6 Other considerations

The RTP labs were chosen by how well they would match the curriculum taught in the lectures. The lecture covers topics in a specific order and our labs tried to follow along so that the lab each week covered the same material that was being taught in lectures. PH1110 starts with a quick discussion of vectors, and then moves into displacement, velocity, and acceleration. The RTP labs we chose always come after the topic addressed in the labs has been taught in lecture. The first two RTP labs also cover those topics. Next the lecture covers Newton's three Laws, which are the subject of the next two RTP labs as well. Finally the lectures end with momentum and collisions, also covered by the last RTP lab.

Shortening the labs consisted of removing the redundancy in the two-hour version. Each lab had 3-4 investigations and each investigation had 3-4 activities. Some of these activities copied each other, calling for the students to repeat something multiple times. We cut that out to save time, thinking that while the repetition is helpful, that is the safest thing to remove without reducing the effectiveness of the labs.

4.4 Implementation of the five active learning labs

The implementation of both versions of the RTP labs used a motion sensor and a force probe attached to a computer. The students used software on the computer to control the sensor and probe to complete the lab. The room had 5 computers, tables for the track and cart, and chairs for the students. It was large enough to allow 10 people, 8 students and 2 instructors, to move around. The computers were spaced out to keep the two groups out of each other's way. The equipment had to be stored out of the way between lab periods and set up just before the lab started.

4.4.1 Equipment list

All of the equipment we used was ordered from Pasco Scientific (www.pasco.com). Each group used one CI-6450 ScienceWorkshop 750 Interface with the DataStudio software. Each group also needed 1 CI-6742 Motion Sensor II, 2 CI-6746 Economy Force Sensor and a ME-9429A Introductory Dynamics System (1.2 m) which contained 2 low friction carts and a 1.2 meter track.

4.4.2 Setting up the lab

Before each lab began, the lab instructors set up all the equipment the students would need. This involved starting the computers, running the software and configuring the probes that would be used. We also set up the track and low friction carts and tested the equipment to make sure it was in good working order. This prep work took approximately 5 minutes. The students did not see the lab write-up ahead of the lab meeting. The students doing the modified one-hour version received the lab when they arrived. The students doing the two-hour labs had the RTP book (Sokoloff, Thornton, Laws, 1999), but were not told which lab they would be doing until they arrived.

4.4.3 Permissions

To modify and reproduce the RTP labs we needed to receive permission from Wiley and Sons, the publisher of the RTP lab book. We sent a letter describing the experiment and stating the page numbers we would be using. Their response was that we would be allowed a one-time only copyright permission as long as we acknowledge the copyright on all copied material. There is copyright information at the bottom of each page of each of our modified labs (see appendix II).

4.4.4 Data Collection for Real Time Physics Labs

The primary source of data was the pre-course and post-course administrations of the FCI exam. All PH1110 students were asked to take the online FCI test. The students were required to take the pre-test during the first week of class and the post-test during the last week of class. The pre- and post-test results were compared to find out how much the students gained understanding. The students' grades were also analyzed as another means of measuring the effectiveness of the labs. Additional data collected included general observations of the students' reaction to the traditional and experimental labs, and an analysis of the students' reactions by means of a survey. The administration of the surveys was done at the last lab. For some of the sections students were given five minutes at the end of the lab to fill out the survey and we collected them before the students left. For others we allowed the students to take the surveys and fill them out in their spare time and had them drop them off in a mailbox together with their final homework.

4.5 Control and experimental groups

There are two PH 1110 lectures in A term; each one contains six sections of approximately 30 students. Each section completes a lab course taught by different professors. The one-hour students were chosen from three of the six sections in one of the two lectures. All 24 Tutorial students went to the first lecture and did the original two-hour RTP labs. An illustration of the divided groups is shown at the end of this section. With this set up, we planned to be able to measure the effectiveness of our one-hour labs versus the RTP two-hour labs versus the original course labs.

4.5.1 Tutorial Experimental Group

The Davis Tutorial group was one section of twenty-four students from the PH1110 course. The criterion used to select this group was that they were all taking the same three classes A and B terms. These students had separate lectures for some of their classes (but not PH1110), and a special conference section for PH1110. They were also allowed to retake tests if they did not perform well. They did the original two-hour versions of the RTP labs and not our modified one-hour versions. The twenty-four students were broken up into three sections of eight students and did the labs at three different lab times. Two groups of four did the labs simultaneously.

4.5.2 Tutorial Control Group

The tutorial control group consisted of PH 1110 students who were taking the same three classes as the tutorial experimental group, and who took both the pre and post FCI test (see section 4.6.4).

4.5.3 One-hour Experimental Group

The experimental group was comprised of students chosen from sections of the PH1110 course that did the modified one-hour versions of the RTP labs. They were chosen at random in the first week of class. We selected 8 students, every fourth name from the class list, and asked them to participate in the labs; if they declined we asked for a volunteer. These students were selected from 3 lab sections, 8 from each of two sections, and only 5 from the third (we were unable to get more than 5 from that section). The students created groups of 4 and 2 groups did the lab at the same time.

4.5.4 One-Hour Control Group

The one-hour control group consisted of students who had FCI scores similar to the experiment students' scores.

Table 1: Split of Control and Experimental groups

	One-hour	Tutorial
Control	Students not doing RTP, from Lecture 1 (N=107)	Students not doing RTP, but taking same 3 classes as Tutorial Students (N=11)
Experimental	24 students doing 1- hour modified RTP labs, from Lecture 2 (N=24)	All 24 Davis Tutorial students doing 2-hour RTP (N=24)

4.6 Methods of Analysis and Assessment

This is a short description of the tests used for analysis of the data. Each test determines the significance of the result in different ways, so it is best to do all three of the tests in order to get a thorough understanding of the data. However, if the number of data points (measured or calculated) being analyzed is too large, then the alternate 4^{th} test may be used.

4.6.1 Exam and Course Grades

We examined the exam and course grades of both the experimental and control to check whether our labs had any statistically significant impact on the students' grades. The exam grades are from four required tests that were administered to the students as part of the course, and the course grades are the students' final grades including homework, tests, and labs.

4.6.2 Pre And Post FCI Data Sample Selection

We assessed the effectiveness of our modified one-hour labs and our implementation of the full RTP labs by analyzing FCI (Force Concept Inventory) scores. The FCI assesses conceptual understanding. The FCI was given as a web based test to all the PH 1110 students (around 500 students) both in the beginning (Pre-Test) of the term and at the end (Post-Test) as an extra credit homework assignment. Of the 415 students who took the pre-test, only 256 took the post-test. We eliminated from the sample students those who were not freshmen and those who had not taken both the pre and post-tests, leaving 118 students to study. In addition, the small number of students who obtained 100% correct on the pre-test were omitted because the FCI loses its accuracy at those levels of conceptual understanding (Karen Cummings, personal communication). These criteria reduced the size of our experimental group to 16 students, with 11 students from our one-hour labs and 5 from our tutorial labs. As a result, our control group for the one-hour students consisted of the remaining 107 freshmen and the control group for the tutorial group consisted of 11 students selected in a manner similar to that of the Tutorial group.

The FCI data can be analyzed by either comparing the post-test score gains $(g = (Post\%)-(Pre\%))$ of an experimental group (one-hour or tutorial) with the post-test score gain of its respective control group or by comparing the normalized learning gain <g> ($\langle g \rangle = \frac{(Post\%)-(Pre\%)}{100-(Pre\%)}$) (Sokoloff, 1999) of the experimental group with its respective control group. The gain comparison is a direct measure of the difference in the final conceptual understanding of the experimental students versus the control students and the comparison of the normalized learning gains of the groups is a direct measure of the difference of the amount of correct physics concepts learned. While the former comparison is on an absolute scale, the latter is not, for if a group were to start out with a lower pre-test score than the other, then the lower group would have more to learn than the group with a higher pre-test score. Comparing the normalized gains is a way of measuring how much the students learned compared to how much they "could have" learned.

4.6.3 Breakdown of the FCI Questions Into Conceptual Topic Groups

In addition to assessing the effectiveness of our labs on the overall conceptual understanding of the students, we also assessed whether or not our labs had an effect on the conceptual understanding of specific physics topics. In order to do this, we grouped all the FCI questions into 7 topic groups that each explored a fundamental concept in physics. The break down of the FCI questions into topic groups were provided by Catherine Crouch of Harvard University as follows:

Topic group	Question Numbers
Gravity	1, 2, 3, 12, 14
Newton's first law	5, 6, 7, 8, 10, 23, 24
Newton's second law	21, 22, 26, 27
Newton's third law	4, 15, 16, 17, 25, 28
Vectors	9
Free body diagrams (FBD)	11, 13, 18, 29, 30
Motion	19, 20

4.6.4 F test

The F test directly measures the significance of any differences between two groups by examining each data point, raw or computed (like g and <g>), in the groups and determining whether or not a model that has the two groups as separate and distinct groups is more valid than a model in which the two groups are essentially the same group. In our case this translates to whether or not our experimental group is distinct from or a subset of our control group. The F value or F_{sig} that results from this test allows us to determine how confident we are that an observed difference in the two groups is significant for the number of subjects we have. In physics education research, a minimum confidence level of 80% is considered acceptable for a significant result and a higher confidence level means a greater certainty that the result is significant (Maxwell, 1999).

4.6.5 D test

The d test determines the minimum number of students needed in each group to claim that the observed difference between the two groups is significant. For example, if it were to determine that we would need a minimum of 50 students to claim a significant result (with 80% or greater confidence) and we have 100, then our result is significant. If, however, we were to only have 25 subjects, then that would mean that our study either did not contain enough students to claim that the difference we are detecting is significant, or that the difference is so small that the we would need a larger sample size to claim a significant difference (Maxwell, 1999).

4.6.6 ϕ test

The ϕ test measures the chance of getting a negative result by determining whether or not the difference between the average of all the data points and the average within each of the groups can be compared based on the number of subjects used in the study. If the difference between our experimental group and our control group is not significant (via the F or D tests), then the ϕ test will determine whether or not a negative result can be measured. This would be detected as a positive result with a low confidence (below 80%) in the F test, or from the D test, it would be detected as a subject sample size that is much greater than the true subject sample size. Conversely, if the difference is significant, the ϕ test can be another way to determine the strength of that significance. If we obtain a true negative result then we could conclude that our experiment had no effect, however, if the lack of difference was not a true negative result then we could not even conclude that the experiment had no effect. All that could be concluded was that the experimental results were not sufficient to reach any conclusion (perhaps due to some artifact of the experiment, like a small sample size). With an 80% confidence level, the ϕ test can determine the chance that our negative result is a true negative result. The ϕ test actually works regardless of whether the initial difference between the two groups is significant (i.e., a positive result or not). In the case of a positive result (from the F test or D test), if the ϕ test says that a negative result is likely then the result is a false positive result. Conversely, if the chance of getting a negative result were small then our result would be more likely to be a true positive result. Due to the similarities among the 3 tests, it is not possible for their results to conflict (Maxwell, 1999).

4.6.7 Alternative Test: Estimation Via The Standard Deviation

If we compare the mean values of our experimental group and our control group with the standard deviation of all the data points over both groups combined (as if they were one big group), we can estimate the significance of the difference between the means for those two groups. If the experimental group mean is less than one standard deviation from the control group mean, then the difference is either not statistically significant or the sample size is not large enough to obtain a significant result. The benefit of this test is that it can be applied quickly and easily to a large number of data points as compared to the former three tests. Unfortunately, this test cannot distinguish an insignificant result from an inconclusive result.

4.6.8 Analyzing Students' Attitudes Via Surveys

Another method of assessing the effectiveness of our labs is to analyze the students' attitudes about the lab course. At the end of the lab course we handed both the Tutorial and One-hour lab students a survey to fill out (see appendix III). We told them the surveys were voluntary. We collected some of the surveys right after they finished it and we received the others in a campus mailbox. Since the surveys were anonymous and since many were collected in a campus mailbox, we had no knowledge of whether the surveys came from the tutorial students or from the one-hour students. In total, we received 32 surveys back out of the 40 that were handed out.

5 Results and Analysis

We analyzed the data collected from the FCI tests, class grades, and surveys to determine how successful this experiment was. The FCI and class grades were used to see if the students gained a better understanding of the concepts in physics. The surveys were used to find if the students enjoyed the experimental labs more than the traditional ones.

5.1 Overview Of FCI Gains By Experimental Group

5.1.1 Post-Test Gain (g) Comparison

In order to measure the effectiveness of our one-hour labs, we compared the final conceptual understanding of the experimental groups with their respective control groups by examining the post-test gain of the FCI scores,

$g = (Post\%)-(Pre\%)$.

5.1.1.1 One-hour Post-Test Gain Vs. One-hour Control

Both the experimental group and the control group had mean pre-test scores of 51%. The post-test gain for the experimental group was 18% whereas the post-test gain for the control group was 15%, as shown in table 5.1.

Table 5.1: FCI Test Score Gain Comparison For 1HR and Its Control Group

	Pre-test %	Post-test%	Post g%
One-hour (N=11)	51%	69%	18%
Control (N=102)	51%	66%	15%

In our analysis, we determined whether or not the experimental group, having a post-test gain that was 3% higher than its control group, was significant. Since the primary objective of our analysis was to determine how this difference reflects the effect our labs had on the students conceptual understanding of physics, we were only concerned with the relative post-test gains between the control and the experimental groups. The results of our F test determined that we are less than 75% confident that our result is significant. The d test determined that we are 80% confident that we only need 8 students to state whether or not the observed difference is significant. Fortunately, we had 11 in our experimental group and 102 in our control group. The ϕ test determined that there is greater than a 99% chance that we have obtained a negative result, or it is likely that there's a lack of a significant difference in the post-test gains of the two groups. From this, we can conclude that the sample size was large enough to observe a significant difference between the two groups, and that we found no significant difference.

5.1.1.2 Tutorial Post-Test Gain Vs. Tutorial Control Post-Test Gain

The experimental group achieved a lower pre-test score of 40% compared to the control group pre-test score of 49%, and achieved a lower post-test gain of 13% compared to the control group's gain of 16%, as shown in table 5.2.

Before we consider the post-test gain result, we must determine whether or not the pre-test score difference is significant and whether it will affect our analysis of the post-test scores. According to the F test, we are much less then 75% confident that the 9% lower pre-test score of the experimental group versus the control group is significant. The d test determined that we are 80% confident that we need 60 students to state whether or not the difference is significant. Unfortunately, we had only 5 in our experimental group and 11 in our control group. The ϕ test determined that we have less than a 20% chance of obtaining a negative result, or that it is only 20% likely that we can conclude anything from the lack of a significant result from the F test. We can conclude that the sample size was not large enough for the difference between the post-test gain of the control group and the post-test gain of the experimental group to be significant.

In our analysis of the post-test gain, we determined whether or not the experimental group, having a post-test gain that is 3% lower than its control group, was significant. The F test determined that we are much less then 75% confident that our result is significant. The d test determined that we are 80% confident that we need 125 students to state whether or not the difference is significant. Unfortunately, we had only 5 in our experimental group and 11 in our control group. The ϕ test determined that we have less than a 10% chance of obtaining a negative result. From this, we may conclude that the difference between the gains of two groups was not significant. The insignificant result may be because either the sample size was not large enough for either the experimental group or the control group, or the result is truly negative. The post-test gains are summarized in Table 5.2.

Table 5.2: FCI Test Score Gain Comparison For Tutorial Its Control Group

	Pre-test %	Post-test%	Post g%
Tutorial (N=5)	40%	53%	13%
Control (N=11)	49%	65%	16%

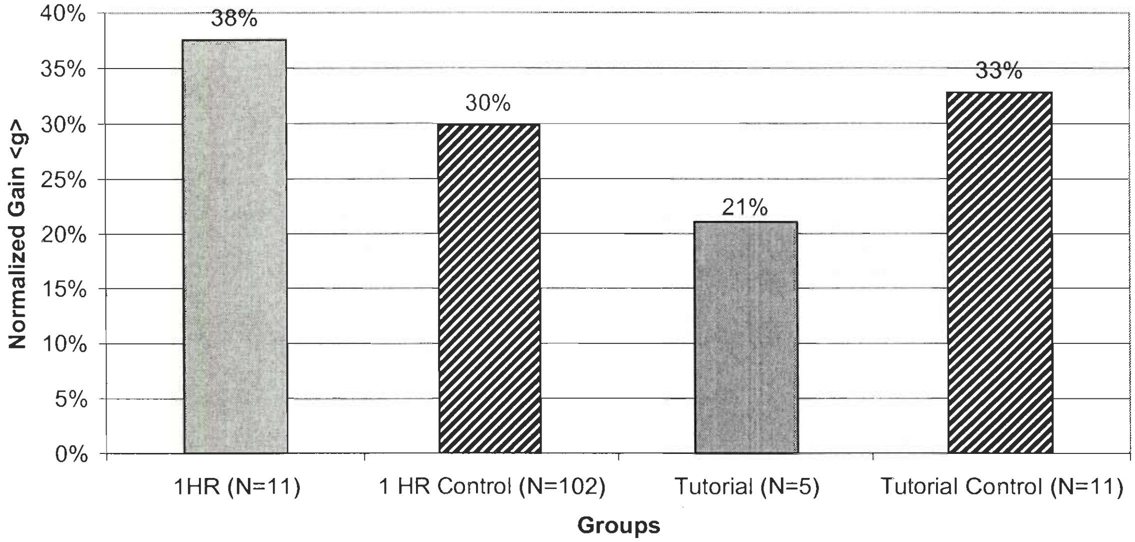
5.1.2 Normalized Learning Gain <g> Comparison

Another way of measuring the effectiveness of our one-hour labs on the conceptual learning gain of the students is to compare the normalized learning gain, $<g>=\frac{(Post\%)-(Pre\%)}{100-(Pre\%)}$, on the FCI of the experimental groups with their respective control groups.

5.1.2.1 One-Hour <g> Vs. One-Hour Control <g>

Even though both the experimental group and the control group started with a pre-test score of 51%, the experimental group achieved a higher normalized learning gain of 38% while the control group achieved a normalized learning gain of 30%, as shown in figure 5.1.

Fig. 5.1: Normalized Gain <g> on FCI For All Groups



We tested whether or not the 8% difference in the normalized learning gain was significant. The F test determined that we are only 75% confident that our result is significant. The d test determined that we are 80% confident that we need 21 students to obtain a significant result. We had 11 in our experimental group and 102 in our control group. The ϕ test determined that we have an 80% chance of obtaining a negative result, or that it is likely that our significant result from the F test is not as significant as it appears. Since our F test showed a significant result of a 75% confidence level, it is likely that even though this result appears to almost be significant, it is more probable that it is not significant at all. From the results of the three tests, we can conclude that the sample size was not large enough for our experimental group (even though it was for our control group) to determine whether or not the difference between the two groups was significant. There is some evidence to suggest that our result is significant, but more tests would have to be done, with a larger sample size, before any conclusions can be drawn.

5.2.1.2 Tutorial <g> Vs. Tutorial Control <g>

The experimental group achieved a normalized learning gain of 21% while the control group achieved a normalized learning gain of 33%, as shown in figure 5.1. As shown in section 5.2.1, the difference in the pre-test score of the control group versus the pre-test score of the experimental group is not large enough to affect our analysis of the data.

In our analysis, we were able to determine whether or not the experimental group, having a normalized learning gain that is 12% lower than its control group, was significant. The F test determined that we are less than 75% confident that our result is significant. The d test determined that we are 80% confident that we need 42 students to state whether or not the difference was significant. We had 5 in our experimental group, and 11 in our control group. The ϕ test determined that we have less than a 30% chance of obtaining a negative result, or that it is only 30% likely that we can conclude anything from the lack of a significant result from the F test. From this we can conclude that the sample size was not large enough, for either the experimental group or the control group, to obtain a significant result.

5.1.3 Summary Of FCI Post-Test and Normalized Gains

In summary, our one-hour labs and the RTP labs, as implemented in the tutorial group, may have had a small effect on how much our experimental students learned in the course overall, as measured by the post-test and normalized gain on the FCI. It may be that the FCI was not sensitive enough to measure the learning gains of the students. So either a larger experimental group is needed for a statistically significant result or the learning gain must be measured with a more sensitive concept test (e.g., FMCE, Force Concept Exam) (Ronald Thornton, personal communication).

5.2 Break Down of FCI Gains by Physics Topic

5.2.1 Data Analysis

After assessing the effect our labs had on overall conceptual understanding, we wanted to evaluate the effect our lab had on the conceptual understanding of the specific physics topics outlined in section 4.6.3. We calculated the average FCI post-test gains in each of the seven topic groups for both the experimental group and the control group and then compared them. As explained in section 4.6.3, the seven physics topic areas that the FCI questions were grouped into are gravity, Newton's first law, Newton's second law, Newton's third law, vectors, free body diagrams (FBD), and motion.

5.2.2 One-Hour group

In the analysis of the understanding of these physics topic groups, we had to analyze at least seven times more data points (including calculated data points) than we did for the overall FCI analysis of the previous section. Due to the time constraints of this IQP, we could not use the more time consuming statistical tests of the previous section. As an alternative, we were able to estimate the significance of any differences between the control group and the experimental group by using the standard deviation test outlined in section 4.6.7.

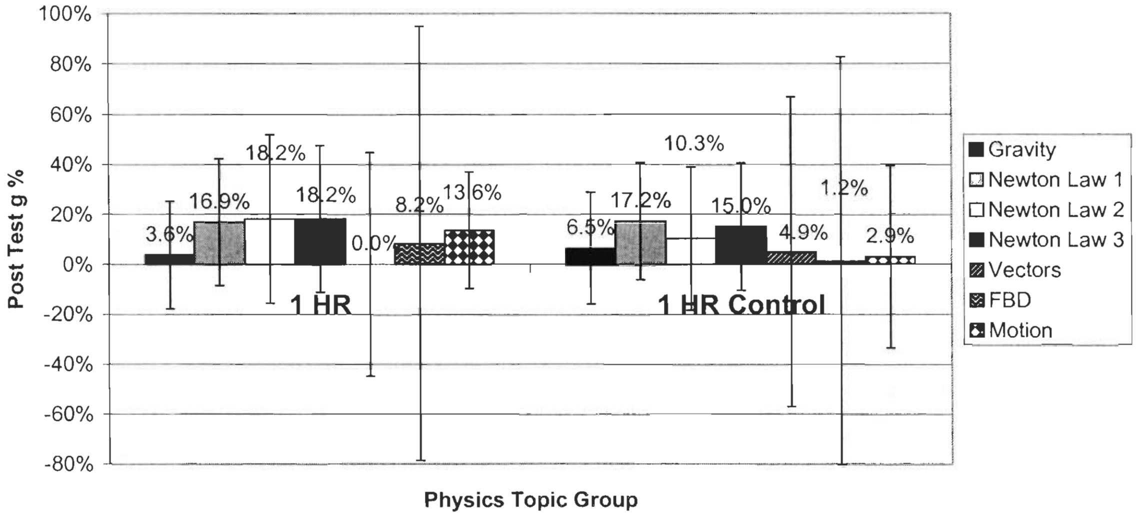
Our results are summarized in figure 5.2. Our labs emphasized four of the seven physics topic areas (Newton's three laws and motion), occasionally touched upon two of the seven topics (FBD's and vectors), and did not cover gravity at all. The traditional labs emphasized a different set of four of the seven topics (Newton's 1^{st} and 2^{nd} laws, vectors, and FBD's), occasionally touched upon gravity, and never touched motion or Newton's 3rd law.

(see section 2.5 for a further discussion of the traditional labs, and section 4.3 for a further discussion of the experimental labs)

The experimental students seem to have shown a small improvement in their post-test gain over the control group (average difference of 7.5%) in four of the six topic areas (Newton's 2nd and 3rd laws, FBD's, and motion) covered by our labs, while showing slight decline over the control group (average difference of -2.6%) in the other two topic areas (Newton's 1st law and vectors). The experimental group showed a post-test gain 2.9% less than the control group on the gravity topic questions.

Despite some of the notable differences between the post-test gain of the experimental group in certain physics topics and the control group, all the experimental group post-test gains were well within one standard deviation of the equivalent control group gain for that same topic group (see figure 5.2). This means that the difference is not significant. A possible explanation for this may be that the FCI is not sensitive enough to accurately measure the difference between the two groups (Ronald Thornton, personal communication).

Fig. 5.2: Comparison of FCI Post-Test Gains by Physics Topic Group for 1-Hour Group and its Control Group



5.3 FCI Gain Analysis By Grade

5.3.1 Data Analysis

In order to determine whether the modified labs benefited students of different academic ability differently, we used the scores from the four exams given over the term of the course in order to match students of similar academic ability. The method by which the Tutorial students' exams were graded was radically different then their control group, so we did not consider them in this academic ability study. The students were grouped into academic ability groups based on their average exam grade over all four exams. The students who had an average exam grade over all four exams that fell between of 90 to 100 were designated exam group "A". Those who had an average exam grade over all four exams that fell between of 80 to 89 were designated exam group "B". Those who had an average exam grade over all four exams that fell between of 70 to 79 were designated exam group "C", and those below 69 were designated group "D and below". Since there was only one one-hour student in the "A" group, we could not compare the control "A" group with the experimental "A" group. An average FCI normalized gain was calculated for each of the three experimental exam groups and each of the three control exam groups. The "B", "C", and "D and below" one-hour group FCI gain averages were then compared to their respective control group gain averages. Using the three statistical tests outlined in sections 4.6.4-6, we were able to determine the significance of the difference between the FCI gains of the experimental exam groups versus their respective control exam groups.

5.3.2 One-Hour Experimental Exam Group vs. Its Respective Control Group

The experimental exam groups' normalized learning gains, and the control exam groups' normalized learning gains, are shown in table 5.3.1.

Table 5.3.1: Comparison of One-Hour group and Its Control Group's Normalized FCI Gains by Exam Group

	B	C	D and Below
One-hour <g>	43% (N=4)	36% (N=3)	28% (N=3)
Control <g>	37% (N=38)	26% (N=25)	10% (N=18)

In our analysis, we were able to determine whether or not the differences between the three experimental exam groups ("B", "C", "D and below") and their respective control groups were significant. The F test has determined that we are less than 75% confident that the differences between the FCI gain of the one-hour and control "B" and "C" exam groups is significant. The F test also determined that we are 81% confident that the one-hour "D" group had a higher normalized gain on the FCI than the control "D" group.

The d test has determined that we are 80% confident that we need 63 students in both "B" groups to obtain a significant result in that for the difference between the one-hour group FCI gain and the control group, 22 students in both "C" groups to obtain a significant result in the "C" group, and 9 students in both "D and below" groups to obtain a significant result for the "D and below" group. Our one-hour groups had 4 students in the "B" group, 3 students in the "C" group, and 3 students in the "D or below" group.

None of the groups was large enough for the differences we detected (with their respective control groups) to be significant.

The ϕ test has determined that we have less than a 30% chance of obtaining a negative result in our comparison of the two "B" groups, less than a 30% chance of obtaining a negative result in our comparison of the two "C" groups, and a 65% chance of obtaining a negative result in our comparison of the two "D and below" groups. From this, we can conclude that we cannot conclude anything about the "B" or "C" groups. Although the result is not definitive, the significant difference we measured between the experimental and control "D and below" group may not be a true positive result. The "D and below" group must be studied further to obtain a more confident result.

5.3.3 All One-Hour Exam Groups vs. All The One-Hour Control Groups

To determine which of the six exam groups ("B", "C","D and below", for both one-hour and control groups) had the greatest gain in their conceptual understanding of physics, we compared all the one-hour exam groups with all the one-hour control exam groups.

In addition to examining whether or not there was any significant difference between the conceptual understanding of physics of each experimental exam group and its respective control exam groups, we compared the conceptual understanding of physics of an experimental exam group with a control exam group other than its equivalent control exam group (i.e., "B group" to "C group" instead of "B group" to "B group"). This analysis was done in a similar manner to the previous section with the comparison of the learning gains and total number of students, and was simplified by the fact that, at least for the experimental exam groups, the number of subjects essentially constant (N=3).

Upon an examination of table 5.3.1, it seems at first that there seems to be a slight increasing trend in the normalized gains of the three experimental exam groups versus as the "grades" increase. Upon closer examination of table 5.3.1, only the difference of 15% between the normalized gain of the "B" experimental group and the "D and below" experimental group is significant. Compared to the difference 18% between the "D and below" experimental exam group and its control exam group, the 15% is similarly significant due to the nearly equal sample sizes. However, we are less than 81% confident that this difference is significant, so it may in fact be only slightly significant.

We also compared all the experimental exam groups with all the one-hour control exam groups, by examining the total number of students in each of the exam groups, as shown in table 5.3.2. Even though there seem to be disproportionately more experimental students in the "C" and "D and below" exam group than corresponding control students in these exam groups, the d test statistical analysis of the previous section clearly shows that we do not have nearly enough students to make such an analysis.

Table 5.3.2: Comparison Of The Number Of Students In Each Exam Group By Percentage Of Total Number of Students

	B	C	D and Below
One-hour (11)	4 (36%)	3 (27%)	3 (27%)
Control (100)	38 (38%)	25 (25%)	18 (18%)

5.3.4 Summary of FCI Analysis By Grade

The one-hour students whose exam average in the course was less than 69% ("D" group) had a significantly higher normalized gain on the FCI than the control group. This may mean that the one-hour "D" students learned more physics concepts than the control "D" group students and that labs helped students with limited academic. As for all the other exam groups, the lack of a significant difference between the control exam group and the experimental exam group may be that the lectures did not teach the concepts addressed by the FCI very well, or that the exam may not test physics concepts as well as they should, or that the FCI was not an accurate measure of physics concepts or was just not sensitive enough to measure the conceptual learning gain (Ronald Thornton, personal communication).

5.4 Analysis of Surveys

5.4.1 Student Attitudes

After analyzing the effectiveness of our labs quantitatively, we wanted to see whether the labs were effective from the students' point of view. In order to do this, we handed out 40 surveys to all our experimental students. Of those 32 were returned, for a response rate of 80%. Students' responses to each question are tallied below.

Question 1: "Did the labs contribute to your learning of physics? Explain."

Out of the 30 students who answered this question, 20 said that the lab course contributed to their understanding, eight said that it did not, and the other two said that the labs helped "sometimes". Here are some typical responses from the students who felt the labs helped them learn:

> "Yes, it helped to visualize and understand why formulas and equations come from and how they were derived."
>
> "Yes. Being able to 'see' the forces, velocities, and accelerations was useful."
>
> "It really helped a lot. We do the experiment and the computer draws the graphs. That really helps a lot and I had a better understanding of it."

The students who responded that the labs did not contribute to their understanding mostly lamented the labs being boring and not coinciding with the lecture. Here are some of their responses:

> "No, I did the same labs in high school, and the labs didn't coincide with the lecture."
>
> "They weren't teaching what we were doing in class."
>
> "I don't think so. I got really bored during all the labs."

Question 2: "Did the lab help you learn concepts that were relevant to the PH 1110 Lecture? Explain."

This second question is more important because it determines whether the students felt that the labs helped them in the course. There were 18 students who thought the labs taught concepts that were relevant, 10 did not, two said some of the labs helped, and two said the graphs helped but nothing else. The students who responded positively said that the labs covered everything taught in lecture, and that the labs helped reinforce concepts taught in lecture with hands on experience.

"Yes, we are going over collisions, force, and everything we covered in the labs."

"Yes. They all dealt with concepts we were learning in PH1110."

"Yes. You were able to see what they talked about in lecture right in front of you."

Those who responded that the labs were not helpful explained in their response that they felt the labs did not coincide with the lecture or that they were confusing.

"Not really, occasionally the lecture and the lab pertained to similar topics, however I frequently had trouble finding the connection."

"Not really, I just got confused most of the time."

"Everything was very confusing, hard to learn."

Question 3: "What could be done to improve the labs?"

For this question 14 of the students pointed out shortcomings of the lab. Of those students, nine thought the labs were repetitive and five thought that the software performed sub-par at times (especially with graphs). Three students also requested that there be a pre-lab lecture given by the lab instructors to explain what they will be covering. Surprisingly, a handful of students wrote that they would like the labs to be harder and to have more questions to answer during the lab.

Here is a sample of the responses:

"Make the graphs on the computer better."

"Less repetitiveness."

"Make them a little harder and don't dwell so much on proving one point."

"Might have a pre-lab discussion to cover the concepts that are going to be discussed."

Question 4: "What did you like most about this lab course?"

Of the 32 who responded only one said that he did not like the lab. Of those 31 students, 15 stated that they enjoyed working with the equipment, four enjoyed the hands on experience, three liked the fact that the labs were easy, three enjoyed the software, three students commented on the unconventional lab reports (which were essentially homework assignments), and three just simply said that the labs were fun. Here are some typical responses:

"It was fun." (3 students)

"It was a good time."

"The hands on learning style of the equipment."

"The gadgets and the toys."

"The computer modeling was fun."

Question 5: "What did you like least about the lab course?"

Of the 31 students who responded to this question, only 13 students took it seriously. Of those 13, four thought the labs were repetitive, six did not like the equipment, two thought the labs were confusing, and one did not like the teaching. Some of the non-serious answers were either “Walking to Founders” or “Waking up”. Here are some examples of the serious responses:

“It was the same thing almost over and over again.”

“Sometimes not being able to get good graphs.”

“The inaccuracy of the computer.”

Question 6: “Would you have liked to have taken the normal labs instead of the computer based labs? Yes/No.”

Of the 32 students that replied, 21 did not want to have done the normal labs, 7 wanted to have the normal labs, and the other 3 said that they were not sure.

5.4.2 Summary of Student Attitude Analysis

The surveys show that the majority of the students felt that the labs were timely and topical and helped them learn the concepts being taught in PH1110. The students who responded that the labs did not help them or that the labs did not coincide with the lecture said they did not understand the concepts being taught or could not make the connection between the labs and lecture. The students who were confused or had trouble making the connection could be helped by implementing one student’s suggestion of instituting a pre-lab talk as is a common practice in the traditional PH1110 labs. This pre-lab session would do a quick review of formulas or concepts from class that would be the focus of their learning in the lab.

As for shortcomings of the labs, some surveys complained of the inaccuracy of the software and repetitiveness. Error and inaccuracy are a reality of labs and this cannot be helped. We noticed the erratic performance of the software, but error and having to do several trials for reliable results is also a reality of labs. The problems could be reduced with having all the software files (which we were missing because the books outdated the software) that calibrate the hardware properly.

As for repetitiveness, unfortunately there is not much that can be done to make the labs diverse because of the fact that the topics discussed in PH1110 are very closely related. In the one-hour labs we tried to limit redundancy as much as possible, but redundancy and repetitiveness is necessary to drive home the concepts. There is not much room for diversification of the exercises, at least with the RTP labs.

However, it is difficult if not impossible to construct any curriculum in which every student is happy. As the old adage goes "You can make some of the people happy all the time but you can't make all the people happy all the time". Judging from the answers to questions 4 and 5, which asked the students what they liked most and least about the labs, the students did enjoy the labs and did not find any major problems. A majority (21 out of 32) of the students did not wish to take the normal labs. Finally, another encouraging sign is the fact that there were responses that stated the labs were "fun".

6. Conclusions

In our analysis of the effectiveness of our experimental labs on the students' conceptual understanding of physics, we found the following:

- There was a small but statistically insignificant effect of the modified labs on FCI normalized gain and post-test gain. Our labs had a small effect on the conceptual understanding of the students.
- The effect of our labs on students' understanding of specific physics topics was statistically insignificant.
- Our labs had no significant effect on the course grades of our students.
- The labs had no significant effect on the conceptual understanding of students of a particular level of academic ability, with one exception. Students with a low academic ability (exam average less than 69%) may have had a better understanding of physics as a result of our labs.
- Students enjoyed our labs and felt that they learned from them. Some also thought that the labs were repetitive and lacked sufficient instruction from the lab instructors.

If our sample size were large enough to show a significant positive result, the effect would still be small. This small effect is contrary to the large effect noticed in other similar implementations of active learning labs (Hestenes, 1992). This could mean one of the following:

1.) There were fundamental flaws in our implementation of the experimental labs (one-hour and 2-hour RTP) that are not readily visible (e.g., inexperienced lab instructors, overly repetitive labs, overly fun labs).

2.) If the experimental labs had an effect on the conceptual understanding of the students, then the effect was probably the same as the traditional labs.

   i. If the experimental labs were as radically different from the traditional labs as we think then perhaps both types of labs had a small effect on the conceptual understanding of the students.

   ii. The experimental labs may not be as radically different from the traditional labs as appear to be.

3.) Our assessment tools (i.e., in class exams and the FCI) were inaccurate.

   i. The FCI is not a good measure of the conceptual understanding of the students.

   ii. The FCI is not sensitive enough to measure the learning gain (positive or negative) of the students in the study.

   iii. The in class exams do not adequately measure the conceptual understanding of physics of the students.

In conclusion, the only evidence that our labs improved student learning is that same students believed that they did. According to results from other similar studies, it seems likely that if our labs had any effect, the FCI may not be sensitive enough to detect it (Ronald Thornton, personal communication).

If this experiment is repeated then a larger experimental sample size is needed. It is highly recommended that a conceptual test other than the FCI be used as a means of assessing the conceptual understanding of the students. Also, a way of ensuring that the experimental students take the conceptual test that does not alter the results is needed; otherwise an even larger experimental sample size would be needed.

If similar labs are implemented in the future, the students seem to believe that a pre-lab overview would be useful. This could be in the form of some formal lab instruction or a pre-lab where the learning objectives of the lab are more clearly stated. Another area for improvement is the use of more accurate software. Software bugs (and other features) sometimes impeded the smooth flow of the lab. When the students could not get the equipment to work, they experienced severe frustration at the cost of the learning objectives of that lab. The final issue to resolve would be to give the labs a less repetitive feel. Often, to get a conceptual point across, the labs will re-examine that conceptual point by several different methods. Even though the students may not understand the physics concept, they can see that the same thing is being said. It might be useful to make this repetition less obvious.

The labs may be a viable replacement for the current labs because they are easy to implement, have no drastically negative effect on the students understanding of physics or on their academic performance, and other studies have shown these labs or similar labs to be highly effective (Sokoloff, Thornton, 1998). More testing on their effectiveness with a larger sample size and a more sensitive conceptual test (e.g., FMCE) will need to be done however before this decision is made.

7. Authorship

This report was written over the course of a year. Originally, the proposal for this project was written by Kevin Rolles and then later edited by Michal Klos. After this series of edits, there were sections added by all members (including David Ramshaw and Seung Wook Kim). Michal Klos added sections, which were subsequently removed because the issues were dropped from the project. Seung Wook Kim and David Ramshaw put together the literature review section, some of which was removed also. The next series of revisions came when the proposal was formed into this report. The entire paper was re-worded and edited by Michal Klos and David Ramshaw. There were many additions made to each section by the two. The Results and Analysis section has components written by all four. Kevin Rolles edited each of those components. The conclusion was written by all four group members. This report has been reviewed by Prof. Judy Miller many times and her suggestions were followed.

8. Acknowledgements

We would like to acknowledge and thank the follow people or organizations: Prof. Judith Miller, for advising us, reading many drafts of this report, and offering advice and guidance; Prof. Tom Keil, for helping with everything from the set up of the room used in our experiments to funding; Prof. Fred Hutson, for helping us to select students to participate in our experiment; Prof. Carolann Koleci, for helping with the data analysis and sharing her research; Prof. Nancy Burnham, for helping in the early steps of the project; Wiley & Sons., for granting us permission to copy and edit the RTP labs; and WPI's Interdisciplinary and Global Studies Department (IGSD), for providing funding for equipment.

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Appendix I: Modified RTP labs

WORCESTER POLYTECHNIC INSTITUTE

PH 1110/1111 - INTRODUCTORY PHYSICS: MECHANICS

Lab 1: Constant Velocity Motion

Instructions: Answer all In-Lab Questions during the lab and make all of your predictions on the data sheet unless otherwise indicated by the instructor. Give the instructor the bad copy of your data sheet and staple the your copy of your data sheet to the **BACK** of your lab report once you have written it.

Objectives:

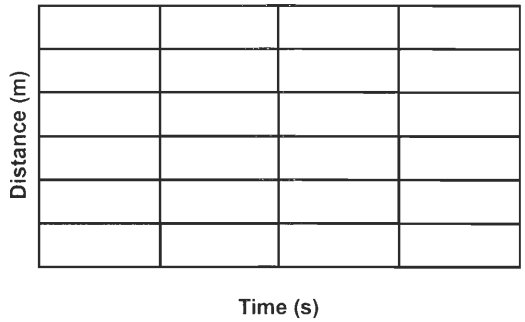
- Learn to use the motion sensor and software
- Learn significant figures
- Learn concept of displacement
- Learn concept of velocity
- Understand the relationship between displacement and velocity

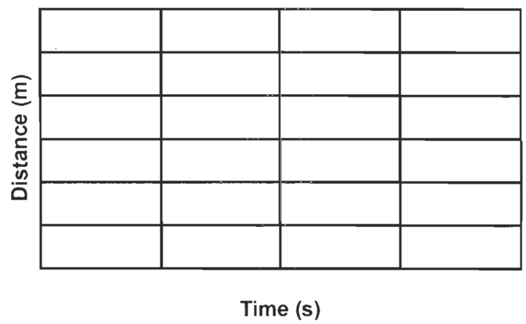
Equipment:

Motion Sensor, meter stick

Procedure:

1. Set up the motion sensor and make 2 distance-time graphs starting ½ meter away from the sensor:
    a. Walk away slowly and steadily:
    b. Walk away quickly and steadily:

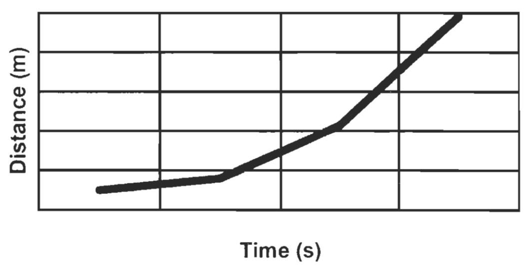




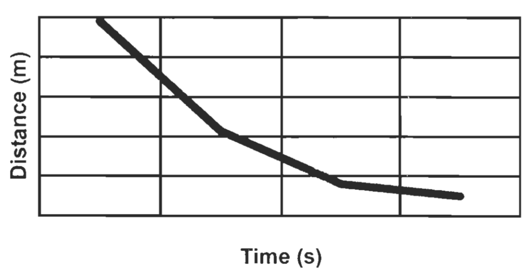
In-lab Question 1: What is the difference between the two graphs?

2. Make a distance-time graph that matches each of the following graphs:

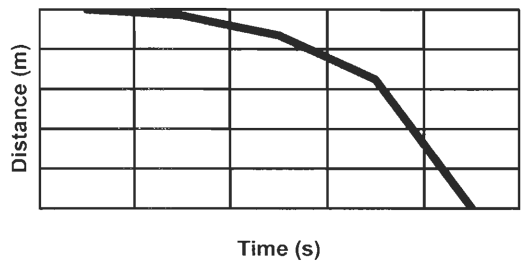
Graph A



Graph B



Graph C



In-lab Question 2: How did you make each of the graphs?

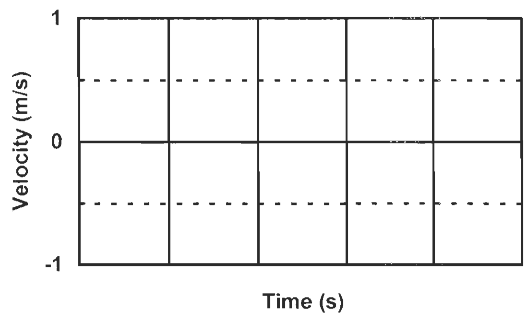
Graph A:

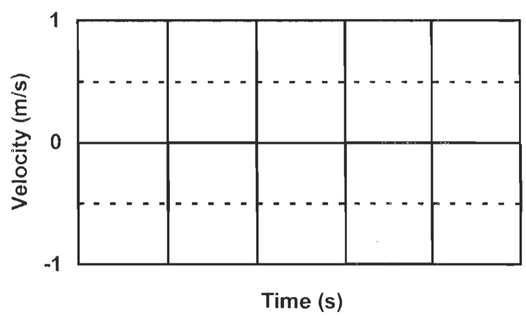
Graph B:

Graph C:

In-lab Question 3: What is the difference between the straight-line graphs and the curved-line graphs?

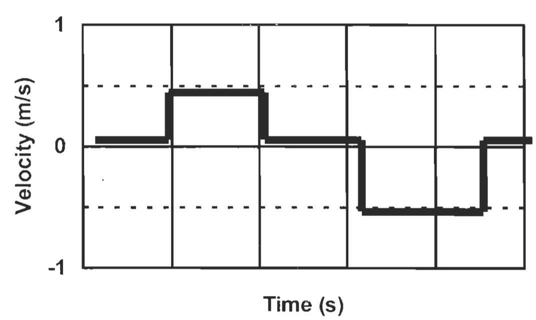
3. Make 2 velocity-time graphs starting ½ meter away from the sensor:
    a. Walk away slowly and steadily:
    b. Walk away quickly and steadily:





In-lab Question 4: What is the difference between the two graphs?

4. Predict what you need to do to match the following velocity-time graph



a. What do you from time 0 to 4s:

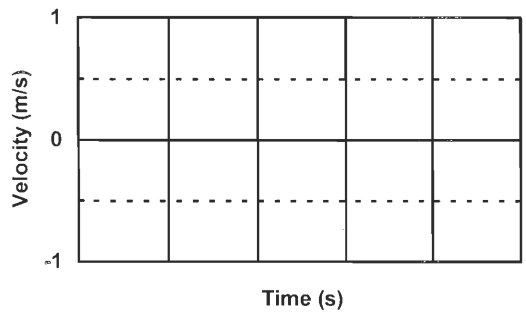
b. 4 to 8s:

c. 8 to 12s:

d. 12 to 18s:

e. 18 to 20s:

5. Make a velocity-time graph based on your predictions:

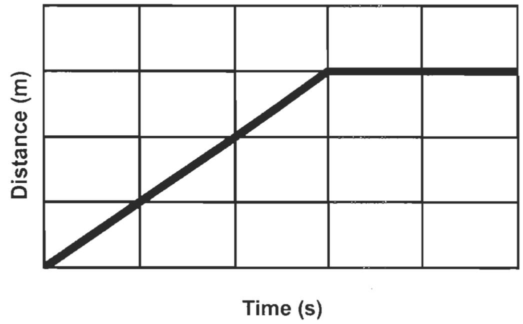


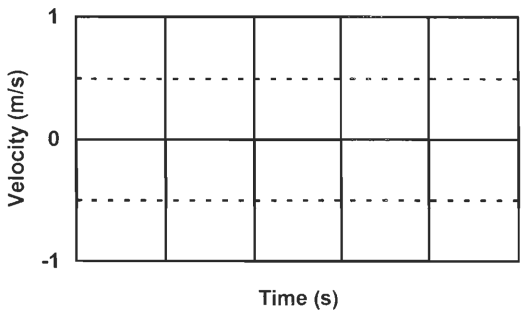
In-lab Question 5: How did you move to match each part of the graph? Did it agree with your predictions?

In-lab Question 6: Can an object move so that it creates a vertical line on a velocity-time graph? Explain.

In-lab Question 7: Did you hit the motion sensor on your return trip? If so, why? How would you solve this? Does a velocity graph tell you where to start?

6. Predict the velocity-time graph from the following distance-time graph:





7. Test your prediction and mark your results on the above graph

In-lab Question 8: How would the distance-time graph look if you moved faster? Slower?

In-lab Question 9: How would the velocity-time graph look if you moved faster? Slower?

8. Use the **table** feature of the software to get 10 values from the velocity-time graph (Note: make sure all values use the correct number of significant digits)

Velocity values (m/s)			
1		6	
2		7	
3		8	
4		9	
5		10	

Average velocity: _____ m/s

9. Calculate the average velocity from the slope of the distance-time graph (Note: make sure all values use the correct number of significant digits)

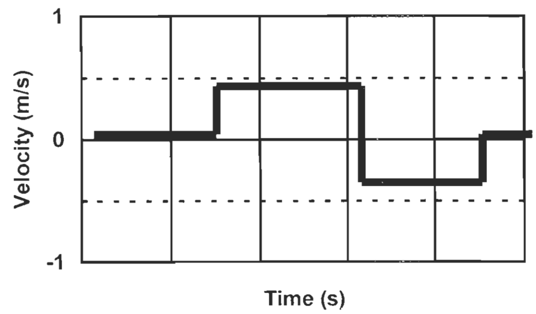
	Position (m)	Time (s)
Point 1		
Point 2		

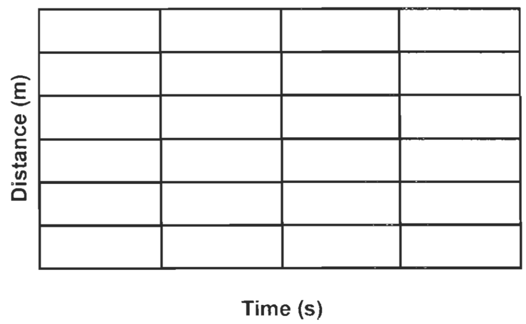
Change in position (m)	
Time interval (s)	
Average velocity (m/s)	

In-lab Question 10: Is the average velocity positive or negative? Is that what you expected?

In-lab Question 11: Do the 2 average velocities match? Is that what you expect? What could cause any differences?

10. Predict the distance-time graph from the following velocity-time graph:





11. Test your prediction and mark your results on the above graph

In-lab Question 12: How can you tell from a velocity-time graph that the object changed direction? What is the velocity at that moment?

In-lab Question 13: How can you tell from a distance-time graph that your velocity is constant?

In-lab Question 14: How can you tell from a velocity-time graph that your velocity is constant?

WORCESTER POLYTECHNIC INSTITUTE

PH 1110/1111 - INTRODUCTORY PHYSICS: MECHANICS

Lab 2: Motion with Changing Velocity

Instructions: Answer all In-Lab questions and make all of your predictions on the data sheet unless otherwise indicated by the instructor. Give the instructor the bad copy of your data sheet and staple the your copy of your data sheet to the **BACK** of your lab report once you have written it.

Objectives:

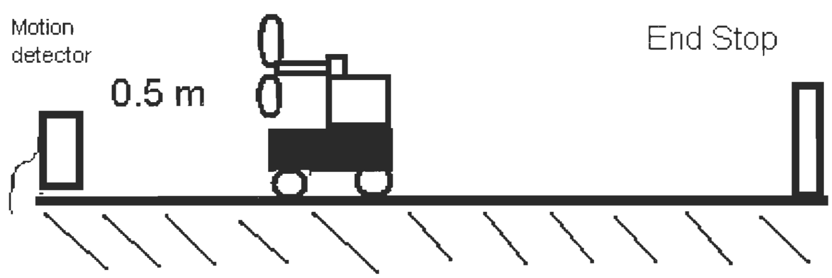
- Understand the meaning of acceleration, its magnitude, and its direction
- Discover the relationship between velocity and acceleration graphs
- Understand how to use vectors to represent velocity and acceleration
- Calculate the average acceleration from acceleration graphs
- Calculate the average acceleration from velocity graph

Equipment:

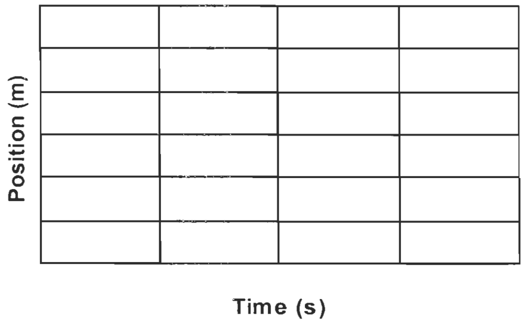
Motion Sensor, cart with very low friction, ramp 2-3 meters long

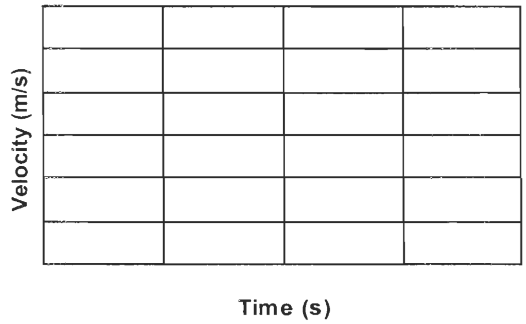
Procedure:

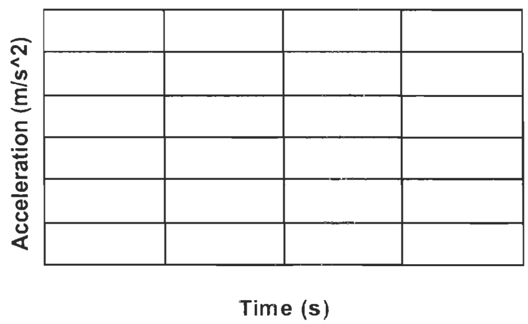
1. Set up the cart on the ramp, with the fan unit and motion detector as shown below.



2. Set the fan to its lowest speed.
3. Begin graphing the position, velocity, and acceleration on the computer. Hold the cart with your hand, switch the fan and the motion detector on, and when you hear the clicks of the motion detector, release the cart from rest. When the cart reaches its end, stop the cart and turn off the fan. Repeat as many times necessary until you get a nice set of graphs.
4. Sketch your results from the computer.







In-lab Question 1. What feature of your velocity graph signifies that the motion was away from the motion detector?

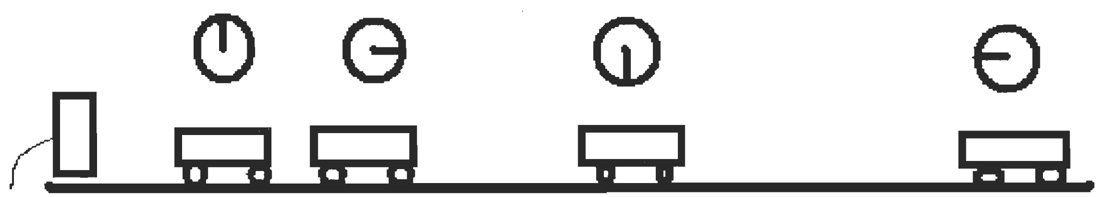
In-lab Question 2. What feature of your velocity graph signifies that the cart was speeding up? How would a graph of motion with a constant velocity differ?

In-lab Question 3. During the time that the cart is speeding up, is the acceleration positive or negative? How does speeding up while moving away from the detector result in this sign of the acceleration? (HINT: Remember that acceleration is the rate of change of velocity. Look at how the velocity is changing. It takes two points on the velocity-time graph to calculate the rate of change of velocity.)

In-lab Question 4. How does the velocity vary in time as the cart speeds up? Does it increase at a steady (constant) rate or in some other way?

In-lab Question 5. How does the acceleration vary in time as the cart speeds up? Is this what you expect based on the velocity graph? Explain.

5. The diagram below shows the positions of a cart at equal time intervals as it speeds up.



At each indicated time, sketch a vector above the cart that might represent the velocity of the cart at that time while it is moving away from the motion detector and speeding up. In your lab write up you need not redraw the entire figure. Merely indicate the vector for a giving instant in time, t.

In-lab Question 6. Show below how you would find the vector representing the change in velocity between the times 1 and 2s in the diagram above. (HINT: remember that the change in velocity is the final velocity minus the initial velocity, and the vector difference is the same as the sum of one vector and the negative of the other vector.)

In-lab Question 7. Based on the direction of this vector and the direction of the positive x axis, what is the sign of the acceleration? Does this agree with the answer to question 3?

6. Find the average acceleration of the cart from your acceleration graph drawn earlier. Use the software to read a number of values (say 10) of the acceleration, which are equally spaced in time.

Acceleration values (m/s^2)			
1		6	
2		7	
3		8	
4		9	
5		10	

Average (mean) acceleration:

The average acceleration during a particular time interval is defined as the average rate of change of velocity with respect to time- the change in velocity divided by the change in time. By definition, the rate of change of a quantity graphed with respect to time is also the slope of the curve. Thus, the (average) slope of an object's velocity-time graph is also the (average) acceleration of the object.

7. Calculate the slope of your velocity graph. Use the software to read the velocity and time coordinates for two typical points on the velocity graph.

	Velocity (m/s)	Time (s)
Point 1		
Point 2		

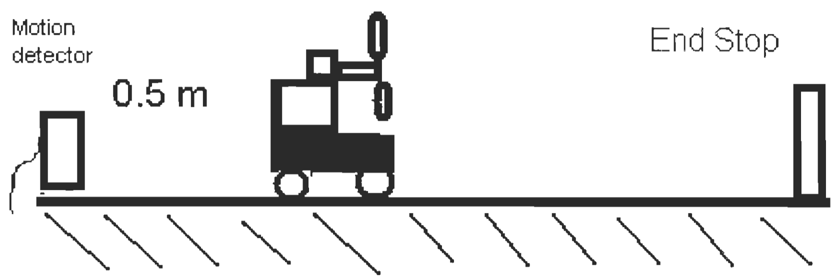
Calculate the change in velocity between points 1 and 2. Also calculate the corresponding change in time (time interval). Divide the change in velocity by the change in time. This is the average acceleration. Show your calculations below.

Speeding up	
Change in velocity	
Time interval	
Average acceleration (m/s^2)	

In-lab Question 8. Is the acceleration positive or negative? Is this what you expected?

In-lab Question 9. Does the average acceleration you just calculated agree with the average acceleration you found from the acceleration graph? Do you expect them to agree? How would you account for any differences?

8. Set up the cart on the ramp, with the fan unit and motion detector as shown below.



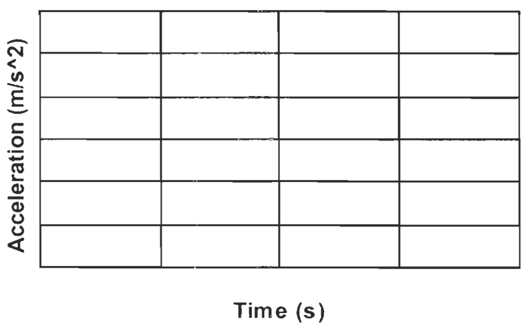
9. Give the cart a quick push away from the motion detector with the fan running, it will slow down after it is released then reverse its direction and speed up in the opposite direction. Stop the cart before it hits the motion detector and turn the fan off. FOR NOW, DO NOT USE THE SOFTWARE TO GRAPH.

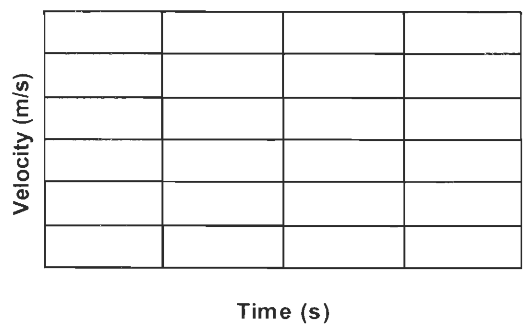
In-lab Question 10. For each part of the motion – away from the detector, at the turning point, and toward the detector – indicate in the table below whether the velocity is positive, zero, or negative. Also indicate whether the acceleration is positive, zero, or negative.

	Moving away	At the turning point	Moving toward
Velocity			
Acceleration			

10. Sketch your predictions of the velocity-time and acceleration-time graphs of this entire motion.

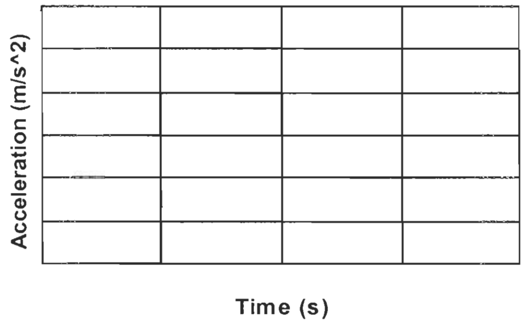
PREDICTIONS

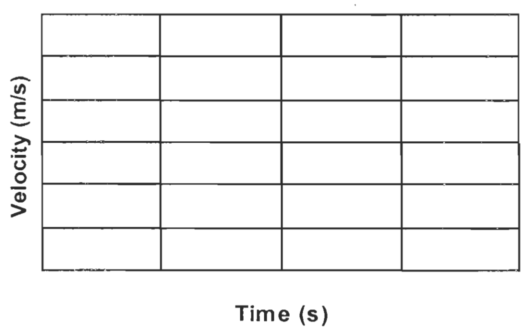




11. Test your predictions by repeating the experiment and using the software to graph. Begin graphing with the back of the cart near the 0.5-m mark. Turn on the fan unit, and when you begin to hear the clicks from the motion detector, give the cart a gentle push away from the detector so that it travels at least 1 m, slows down, and then reverses its direction and moves toward the detector. Push and stop the cart with your hand on its side. Be sure that your hand is not between the cart and the detector. Be sure to stop the cart at least 0.5-m from the motion detector and turn off the fan unit immediately.

FINAL RESULTS





Label both graphs with:

1. **A** where the cart started being pushed.
2. **B** where the push ended (where your hand left the cart)
3. **C** where the cart reached its turning point (and was about to reverse direction).
4. **D** where you stopped the cart.

Explain how you know where each of these points is.

In-lab Question 12. Did the cart "stop" at its turning point? (HINT: Look at the velocity graph. What was the velocity of the cart at its turning point?) Does this agree with your prediction? How much time did it spend at the turning point velocity before it started back toward the detector? Explain.

In-lab Question 13. According to your acceleration graph, what is the acceleration at the instant the cart reaches its turning point? Is it positive, negative, or zero? Is it significantly different from the acceleration during the rest of the motion? Does this agree with your prediction?

In-lab Question 14. Explain the observed sign of the acceleration at the turning point. (HINT: Remember that acceleration is the rate of change of velocity. When the cart is at its turning point, what will its velocity be in the next instant? Will be positive or negative?)

WORCESTER POLYTECHNIC INSTITUTE

PH 1110/1111 - INTRODUCTORY PHYSICS: MECHANICS

Lab 3: Force and Motion

Instructions: Answer all In-Lab questions and make all of your predictions on the data sheet unless otherwise indicated by the instructor. Give the instructor the bad copy of your data sheet and staple the your copy of your data sheet to the **BACK** of your lab report once you have written it.

Objectives:

- To learn how to use a force probe to measure force
- To explore how the motion of an object is related to the forces applied to it.
- To find a mathematical relationship between the force applied to an object and its acceleration.

Overview

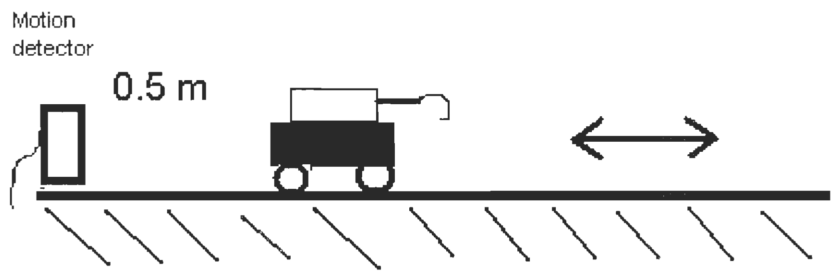
In the previous labs, you have used a motion detector to display position-time, velocity-time, and acceleration-time graphs of different motions of various objects. You were not concerned about how you got the objects to move, i.e., what forces (pushes or pulls) acted on the objects. From your own experiences, you know that force and motion are related in some way. To start your bicycle moving, you must apply a force to the pedal. To start up your car, you must step on the accelerator to get the engine to apply a force to the road through the tires.

But exactly how is force related to the quantities you used in the previous lab to describe motion-position, velocity, and acceleration? In this lab you will pay attention to forces how they affect motion. By applying forces to a cart and observing the nature of its resulting motion graphically with a motion detector, you will come to understand the effects of forces on motion.

Equipment: force probe, motion detector, spring scale with maximum reading of 5 N, cart with very little friction, masses to increase cart's mass, smooth ramp 2-3 m long, low friction pulley, lightweight string, table clamp, variety of hanging masses.

Proceduce:

1. Set up the cart, the force probe, and the motion detector on the ramp as shown below.



The force probe should be fastened securely to the cart so that its body do not extend beyond the end of the cart facing the motion detector.

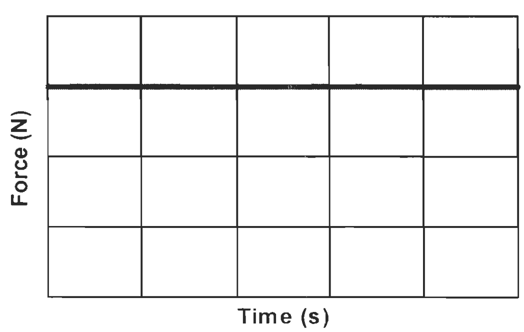
2. Suppose you grasp the force probe hook and move the cart forward and backward in front of the motion detector. Do you think that either the velocity or the acceleration graph will look like the force graph? Is either of these motion quantities related to force? (That is to say, if you apply a changing force to the cart, will the velocity or acceleration change in the same way as the force?) Explain.

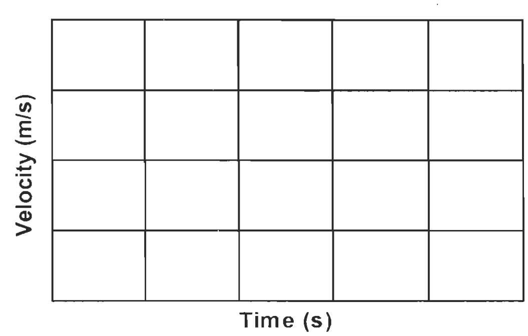
3. Now it's time to test your predictions using the software. Zero the force probe. Grasp the force probe hook and begin graphing. When you hear the clicks, quickly pull it back toward the motion detector and again quickly stop it. Then quickly push it back toward the motion detector and again quickly stop it. Pull and push the force probe hook along a straight line parallel to the ramp. Make sure you graph 3 separate graphs in the computer: velocity vs time, force vs time, and acceleration vs time.

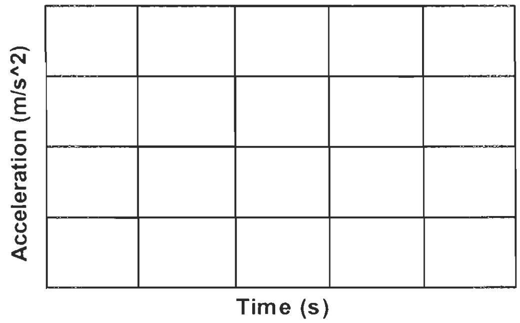
In-lab Question 1. Does either graph - velocity or acceleration - resemble the force graph? Which one? Explain.

In-lab Question 2. Based on your observations, does it appear that there is a mathematical relationship between either applied force and velocity, applied force and acceleration, both, or neither? Explain.

In-lab Question 3. Suppose that you have a cart with very little friction and you pull this cart with a constant force as shown below on the force-time graph. Sketch on the axes below your predictions of the velocity-time and acceleration-time graphs of the cart's motion.

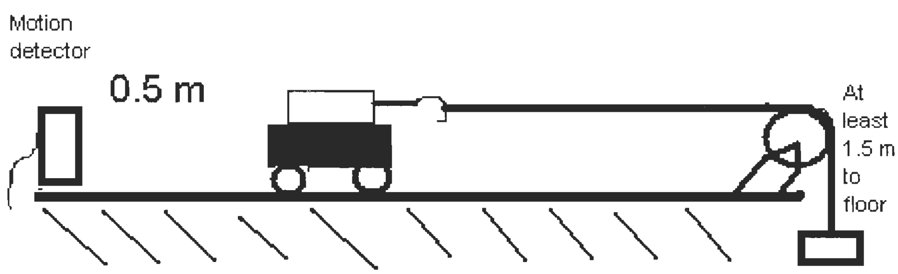






Describe in words the predicted shape of the velocity vs time and acceleration vs time graphs that you sketched.

4. Set up the ramp, pulley cart, string, motion detector, and force probe as shown below. The cart should be the same mass as before.



It's important to choose the amount of falling mass so the cart doesn't move too fast to observe the motion. Experiment with different hanging masses until you can get he cart to move across the ramp in about 2-3 s after the mass is released.

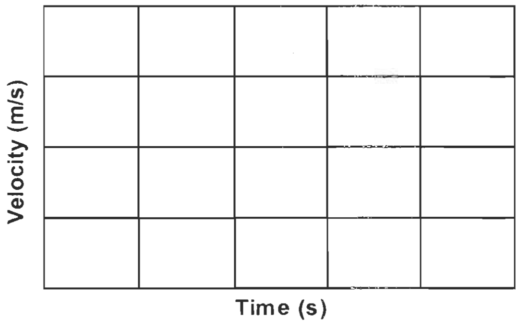
Record the hanging mass that you decided to use:

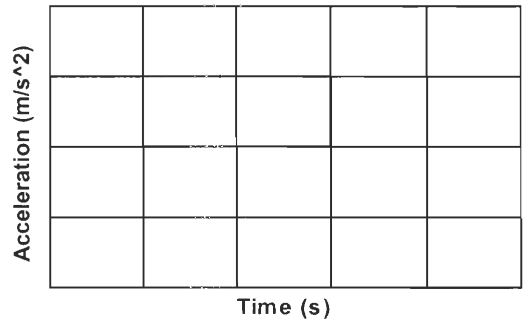
5. Calibrate the force probe with a force of 2.0 N applied to it with the spring scale.

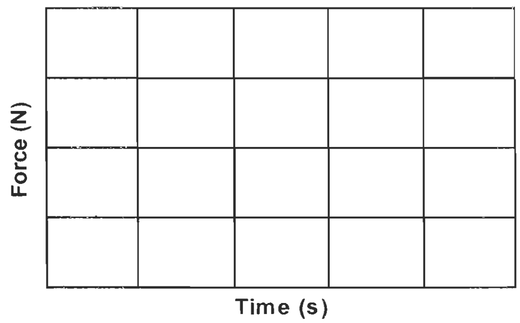
6. Zero the force probe with the string hanging loosely so that no force is applied to the probe. Zero it again before each graphing.

7. Begin graphing. Release the cart after you hear the clicks of the motion detector. Repeat until you get good graphs in which the cart is seen by the motion detector over its whole motion.

8. Sketch the results below.







9. Use the software to measure the average force and the average acceleration.
Average Force (N):
Average Acceleration (m/s^2):

In-lab Question 4 After the cart is moving, is the force that is applied to the cart by the string constant, increasing, or decreasing? Explain based on your graph.

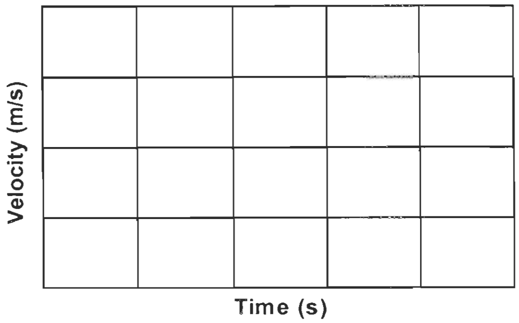
In-lab Question 5 How does the acceleration graph vary in time? Does this agree with your prediction? Does a constant applied force produce a constant acceleration?

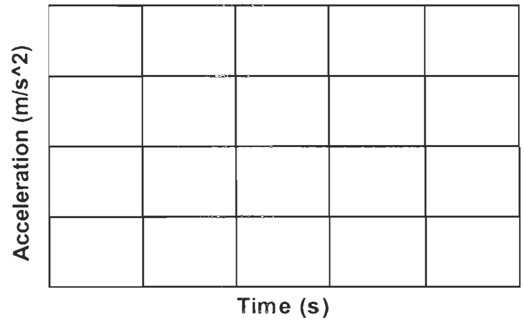
In-lab Question 6 How does the velocity graph vary in time? Does this agree with your prediction? What kind of change in velocity corresponds to a constant applied force?

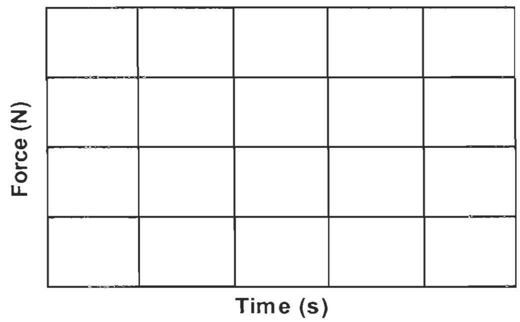
9. Repeat steps 4-8 with a force about twice as large as before. Predict what would happen to the acceleration of the cart? Explain.

10. Test your prediction. Graph force, velocity, and acceleration below as before. *Don't forget to zero the force probe with nothing attached to the hook right before graphing.*

Record the hanging mass that was used:





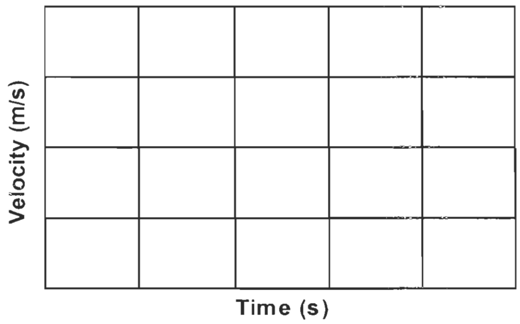


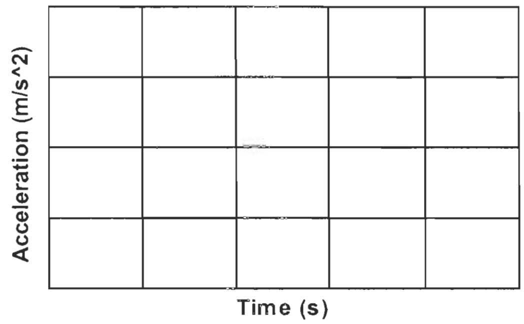
11. Use the software to measure the average force and average acceleration for this investigation, and record the values.
Average Force (N):
Average Acceleration (m/s^2):

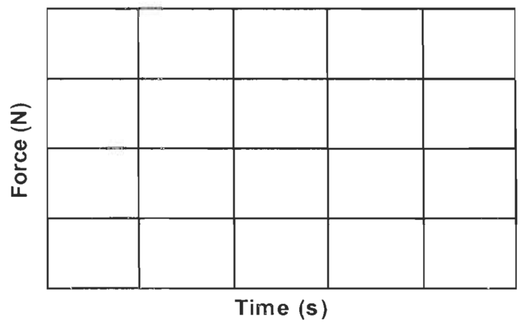
12. Repeat steps 4-8 with a force midway between the other two forces you applied. Predict what would happen to the acceleration of the cart? Explain.

13. Test your prediction. Graph force, velocity, and acceleration below as before. *Don't forget to zero the force probe with nothing attached to the hook right before graphing.*

Record the hanging mass that was used:







14. Use the software to measure the average force and average acceleration for this investigation, and record the values.
Average Force (N):
Average Acceleration (m/s^2):

In-lab Question 7 How did the force applied to the cart compare to that with the smaller force in Investigation 2, and bigger force in Investigation 3?

In-lab Question 8 How did the acceleration of the cart compare to that caused by the smaller force in Investigation 2 and Investigation 3? Did this agree with your predictions? Explain.

15. Plot a graph of acceleration vs force using the mean force and the mean acceleration from Investigation 2, 3,and 4.

16. Use the FIT ROUTINE to determine the mathematical relationship between the acceleration of the cart and the force applied to the cart as displayed on your graph.

17. Print your graph along with the fit equation and affix it in the space below.

In-lab Question 9 Does there appear to be a simple mathematical relationship between the acceleration of a cart (with fixed mass and negligible friction) and the force applied to the cart (measured by the force probe mounted on the cart)? Write down the equation you found and describe the mathematical relationship in words.

In-lab Question 10 If you increased the force applied to the cart by a factor of 10, how would you expect the acceleration to change? How would you expect the acceleration-time graph of the cart's motion to change? Explain based on your graphs.

In-lab Question 11 If you increased the force applied to the cart by a factor of 10, how would you expect the velocity-time graph of the cart's motion to change? Explain based on your graphs.

COMMENT: The mathematical relationship that you have been examining between the acceleration of the cart and the applied force is known as *Newton's second law*.

WORCESTER POLYTECHNIC INSTITUTE

PH 1110/1111 - INTRODUCTORY PHYSICS: MECHANICS

Lab 4: Collisions

Instructions: Answer all In-Lab In-lab Questions and make all of your predictions on the data sheet unless otherwise indicated by the instructor. Give the instructor the bad copy of your data sheet and staple the your copy of your data sheet to the **BACK** of your lab report once you have written it.

Objectives:

- To understand momentum and impulse
- To study the interaction of forces during collisions
- To understand elastic and inelastic collisions

Equipment:

Low-friction cart, meter stick, ramp, motion detector, clay, rubber stopper, force probe, springy wall

Introduction:

Lets test your intuition about momentum and forces. You are sleeping in your sister's room while she is away at college. Your house is on fire and smoke is pouring into the partially open bedroom door. To keep the smoke from coming in, you must close the door. The room is so messy that you cant get to the door. The only way to close the door is to throw either a blob of clay or a superball (super-bouncy ball) at the door – there isn't time to throw both.

Let's investigate which object would be the right choice and compare the maximum force imparted to the force probe from the two types of collisions.

Procedure:

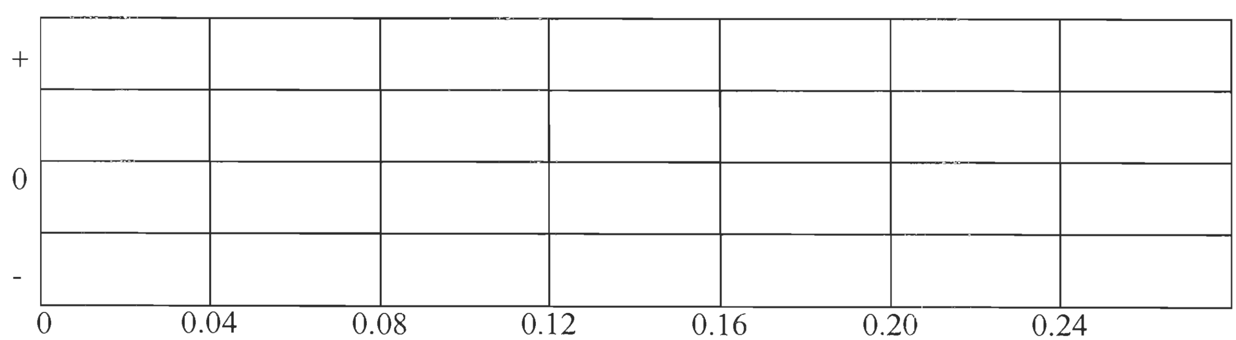
1. Open the experiment file called Clay vs. Superball (L8A1-2) . This will set up the computer to collect and graph force data at 4000 points per second in triggered mode with a push as positive, on the axes that follow.
2. Mount the rubber stopper on the end of the force probe.
3. Zero the force probe while holding it in a vertical position with the stopper pointing down. Begin with the rubber stopper 10 cm above the table (Record the height in Table 1-1)

Table 1-1

	Mass (kg) including probe	Height (m)	Maximum Force (arbitrary units)
Stopper			
Small clay ball			
More massive clay ball			
Small clay ball, larger height			

4. Begin graphing, and then drop the force probe. Repeat this several times, zeroing the force probe before each measurement. *Be sure that the force probe falls vertically downward and doesn't tip to one side.*

5. Move the data from your last good run so that the graphs are persistently displayed on the screen for later comparison.
6. Use the analysis feature of the software to find the maximum force applied to the force probe, and record it in Table 1-2.
7. Now replace the stopper with a ball of clay of about the same mass. Be sure to zero the force probe with the clay pointing vertically downward before beginning to graph.
8. Drop the force probe from the same height, find the maximum force and record it in the table. Also record the masses of the stopper plus force probe and clay plus force probe, and the height of the drop.
9. Sketch both graphs on the following axes



In-lab Question 1: Which object resulted in the bigger maximum force – the stopper or the clay?

In-lab Question 2: Based on your observations, which should you throw at the door – the superball or the clay? Explain.

Prediction: Which object undergoes the greater momentum change during the collision with a door – the clay blob or the superball? Explain your reasoning carefully.

Check your prediction with some calculations of the momentum changes for both collisions that you carried out. This is a good review of the properties of one-dimensional vectors. Carry out the following calculations for the original height and original mass of both the stopper and clay ball.

1. Calculate the initial momentum of the clay ball plus force probe just before it hits the table. (Hint: You will need to call from kinematics with constant acceleration that $v = (2a_g h)^{1/2}$, where $a_g = 9.8\ m/s^2$ is the gravitational acceleration, and h is the distance the ball falls before hitting the table.) Take the positive y axis as upward, Show your calculation.

   $P_{i\,=}$

2. What is the final momentum of the clay ball and force probe after it collides with the table? Explain.

   $P_{j\,=}$

3. What is the change in momentum of the clay ball and force probe? Be careful of the sign.

   Clay ball : $\Delta p =$

4. Now calculate the change in momentum of the stopper and force probe from just before it hits the table until just after it bounces up from the table. Assume that the stopper bounces in such a way that the magnitude of its velocity doesn't change. Show your calculation below. Be very careful of signs!

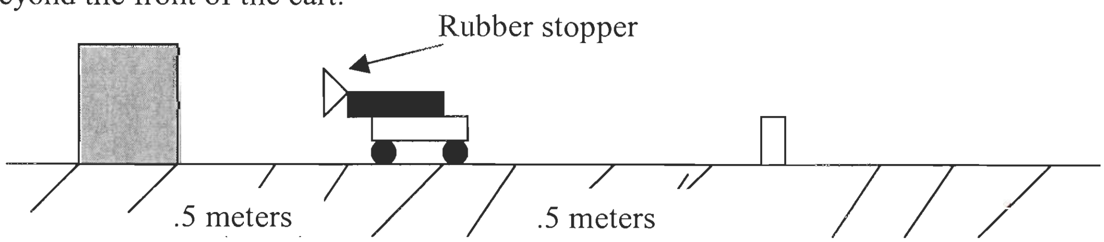
   Stopper : $\Delta p =$

In-lab Question 3 Compare your calculated changes in momentum to your predictions. Do they agree? Which ball had the larger change in momentum?

In-lab Question 4 How does the ball change in momentum seem to be related to the maximum force applied to the ball?

In a perfectly elastic collision between a cart and a wall, the cart would recoil with exactly the same magnitude of momentum that if had before the collision. Because your cart's spring bumper is not perfect, you can only produce a *nearly* elastic collision.

1. Fasten the force probe securely to the cart so that the rubber stopper extends beyond the front of the cart.

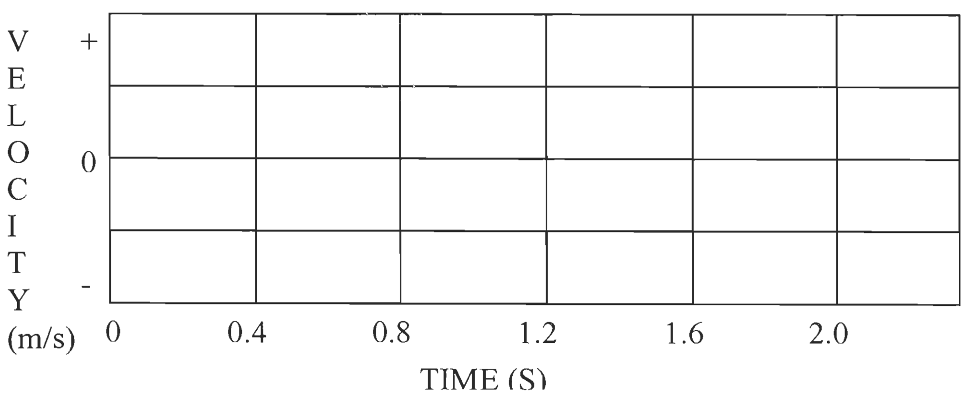


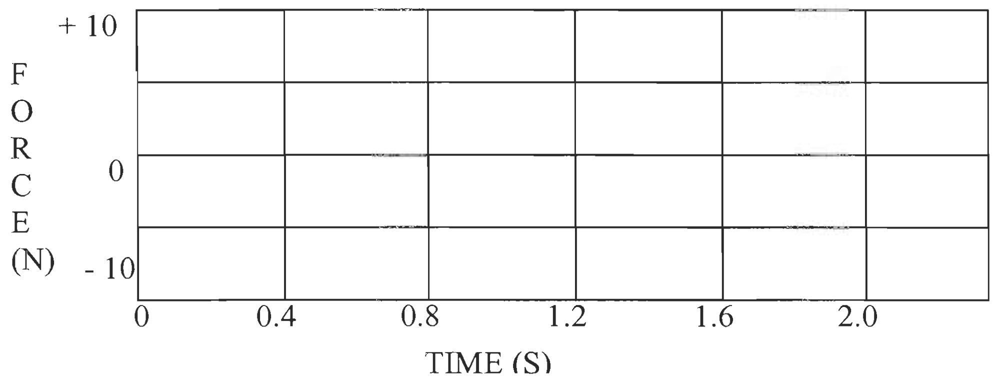
2. Set up the motion detector as shown. *Be sure that the ramp is level.*

3. Measure the mass of the cart and force probe combination.

Mass of the cart plus force probe _______ kg

4. Open the experiment file called Impulse and Momentum (L8 A2-2) to display the axes that follow. This experiment has been set up to record force and motion data at 50 data points per second. Because the positive direction is toward the right, the software has been set up to record a push on the force probe as a positive force, and velocity toward the motion detector as positive.
5. Calibrate the force probe for a push of 9.8 N by holding the cart with the rubber stopper pointing up and balancing a 1.0-kg mass (9.8 N weight) on the stopper, or load the calibration.





6. Be sure that the wire from the force probe is taped out of the way, so that it wont be seen by the motion detector.
7. Practice pushing the cart toward the wall and watching it bounce off. Find a way to push without putting your hand between the motion detector and the cart.
8. When you are ready, zero the force probe and then begin graphing. As soon as you hear the clicking of the motion detector, give the cart a push toward the wall, release it, and let it collide.

Repeat until you get a good set of graphs, i.e., a set in which the motion detector saw the relatively constant velocities of the cart as it moved toward the wall and as it moved away, and also the maximum force was no more then 10 N. (With too large a force, the force probe may read inaccurately.)

9. Use the analysis and statistics features in the software to measure the average velocity of the cart as it approached the wall, and the average velocity as it moved away from the wall.
   Don't forget to include a sign. Positive velocity should be away from the wall.

Average velocity toward the wall: _____ m/s

Average velocity away from the wall: ______ m/s

10. Calculate the change in momentum of the cart. Show your calculations.

$\Delta p =$ ______ kg m/s

11. Use the integration routine in the software to find the area under the force-time graph – the impulse. (The area under a curve is the same as the integral of force vs. time.)

J = ______ N •s

12. Sketch your graphs on the axes above.

In-lab Question 5 Did the calculated change in momentum of the cart equal the measured impulse applied to it by the wall during the nearly elastic collision? Explain.

What would the impulse be if the initial momentum of the cart were larger? What if the collision were inelastic rather then elastic, i.e., what if the cart stuck to the wall after the collision?

WORCESTER POLYTECHNIC INSTITUTE

PH 1110/1111 - INTRODUCTORY PHYSICS: MECHANICS

Lab 5: Collisions Part II

Instructions: Answer all In-Lab In-lab Questions and make all of your predictions on the data sheet unless otherwise indicated by the instructor. Give the instructor the bad copy of your data sheet and staple the your copy of your data sheet to the **BACK** of your lab report once you have written it.

Objectives:

- Understand Newton's third law as applied to collisions.
- Understand the law of conservation of momentum.
- Explore conservation of momentum.

Equipment:

Two force probes with rubber stoppers, two 1 kg masses, two low-friction carts, extra masses, clay, ramp.

Introduction:

There are many situations where objects interact with each other, for example, during collisions. In this investigation we want to compare the forces exerted by the objects on each other. In a collision, both objects might have the same mass and be moving at the same speed, or one object might be much more massive, or they might be moving at very different speeds. What factors might determine the forces the objects exert on each other? Is there some general law that relates these forces?

Procedure:

Prediction 1: Suppose two objects have the same mass and are moving toward eachother at the same speed so that $m_1 = m_2$ and $v_1 = -v_2$ (same speed, opposite direction).

Predict the relative magnitudes of the forces between object 1 and object 2 during the collision. Place a check next to your prediction.

______ Object exerts a larger force on object 2.

______ The objects exert the same size force on each other.

______ Object 2 exerts a larger force on object 1.

Prediction 2: Suppose the masses of two objects are the same and that object 1 is moving toward object 2, but object 2 is at rest.

$$m_1 = m_2 \text{ and } v_1 \neq 0,\ v_2 = 0$$

Predict the relative magnitudes of the forces between object 1 and object 2 during the collision.

_____ Object 1 exerts a larger force on object 2.

_____ The objects exert the same size force on each other.

_____ Object 2 exerts a larger force on object 1.

Prediction 3: Suppose the mass of object 1 is greater than that of object 2 and that it is moving toward object 2, which is at rest.

$$M_1 > m_2 \text{ and } v_1 \quad 0,\ v_2 = 0$$

Predict the relative magnitudes of the forces between object 1 and object 2 during the collision.

_____ Object 1 exerts a larger force on object 2.

_____ The objects exert the same size force on each other.

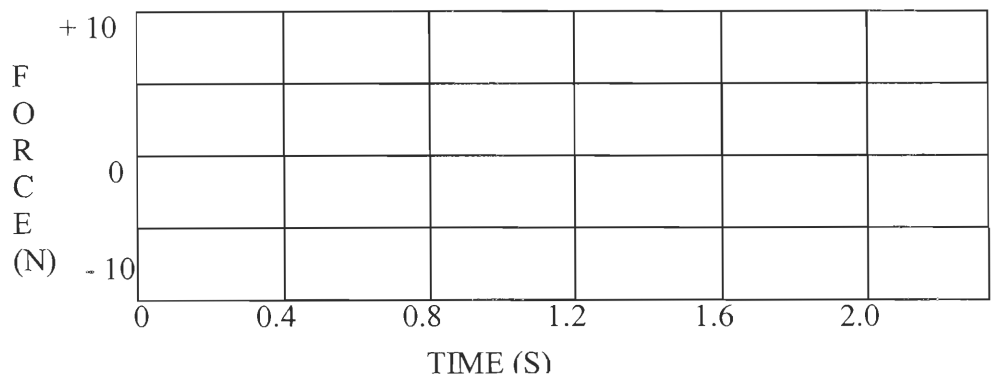
_____ Object 2 exerts a larger force on object 1.

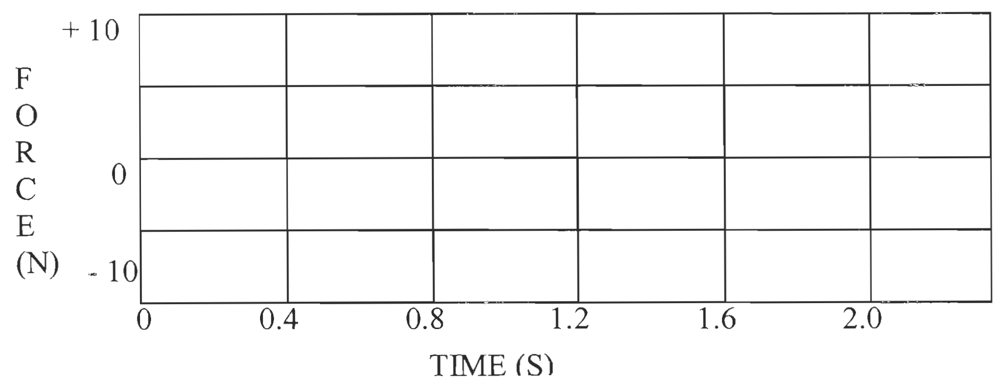
Provide a summary of your predictions. What are the circumstances under which you predict that one object will exert a greater force on the other object?

To test the predictions you made you can study gentle collisions between two force probes attached to carts. You can add masses to one of the carts so it has significantly more mass than the other. If a compression spring is available you can also study an "explosion" between the two carts by compressing the spring between the force probes on each cart and letting it go.

10. The hooks on the force probes should be replaced by rubber stoppers, which should be carefully aligned so that they will collide head-on with each other.

11. Open the experiment file called Collisions (L9 A1-1) to display the axes shown below. The software will be set up to measure the forces applied to each probe with a very fast data collection rate of 4000 points per second. (This allows you to see all of the details of the collision which takes place in a very short time interval.) The software will also be set up to be triggered, so that data collection will not start until the carts actually collide.





12. Calibrate both force probes for pushes with 1.0 kg (9.8 N) masses balanced on each stopper, or load the calibrations. You may find it easier to calibrate one force probe at a time.
13. Reverse the sign of force probe 1, since a push on it is negative (toward the left).
14. Use the two carts to explore various situations that correspond to the predictions you made about the interaction forces. Your goal is to find out under what circumstances one cart exerts more force on the other.
    Try collisions (a) – (c) listed below.
    Be sure to zero the force probes before each collision. Also be sure that the forces during the collisions do not exceed 10 N.
    Sketch the graphs for each collision on the previous axes. Be sure to label your graphs.

For each collision use the integration routine to find the values of the impulses exerted by each cart on the other (i.e., the areas under the force0time graphs). Record these values in the spaces below and carefully describe what you did and what you observed.

(a) Two carts of the same mass moving toward each other at about the same speed.

(b) Two carts of the same mass, one at rest and the other moving towards it.

(c.) One cart twice or three times as massive as the other, moving toward the other cart, which is at rest.

In-lab Question 1: Did your observations agree with your predictions? What can you conclude about forces of interaction during collisions? Under what circumstances does one object experience a different force than the other during a collision? How do forces compare on a moment by moment basis during each collision.?

In-lab Question 2: You have probably studied Newton's third law in lecture or in your text. Do your conclusion shave anything to do with Newton's third law? Explain.

In-lab Question 3: How does the impulse due to cart 1 acting on cart 2 compare to the impulse of cart 2 acting on cart 1 in each collision? Are they the same in magnitude or different? Do they have the same sign or different signs?

Interaction forces between two objects occur in many other situations beside collisions. For example, suppose that a small car pushes a truck with a stalled engine. The mass of object 1 (the car) is much smaller than object 2 (the truck). At first the car doesn't push hard enough to make the truck move. Then, as the driver pushes harder on the gas pedal, the truck begins to accelerate. Finally, the car and truck are moving along at the same constant speed.

Prediction 4 : Place a check next to your predictions of the relative magnitudes of the forces between object 1 and object 2.

Before the truck starts moving:

_____ the car exerts a larger force on the truck.

_____ the car and truck exert the same size force on each other.

_____ the truck exerts a larger force on the car.

While the truck is accelerating:

_____ the car exerts a larger force on the truck.

_____ the car and truck exert the same size force on each other.

_____ the truck exerts a larger force on the car.

After the car and truck are moving at the same speed:

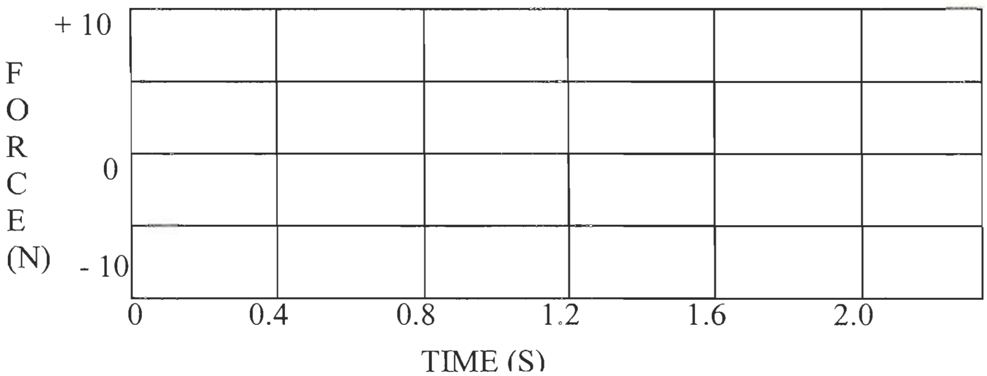
_____ the car exerts a larger force on the truck.

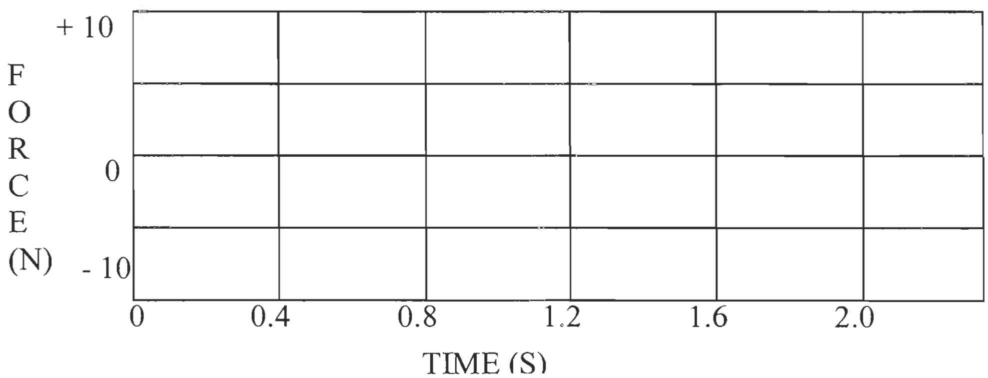
_____ the car and truck exert the same size force on each other.

_____ the truck exerts a larger force on the car.

Test your predictions.

1. Open the experiment file called Other Interactions (L9 A1-2) to display the axes that follow. The software is now set up to display the two force probes at a slower data rate of 20 points per second.





2. Use the same setup as in Investigation 1 with the two force probes mounted on carts. Add masses to cart 2 (the truck) and make it much more massive that cart 1 (the car) (two or three times as massive.)
3. Zero both force probes just before you are ready to take measurements.
4. Your hand will be the engine for cart 1. Move the carts so that the stoppers are touching, and then begin graphing. When the graphing begins, push cart toward the right. At first hold cart 2 so it cannot move, but then allow the push of cart 1 to accelerate cart 2, so that both carts move toward the right, finally at a constantly velocity.
5. Sketch your graphs on the axes above.

In-lab Question 4: How do your results compare to your predictions? Is the force exerted by cart 1 on cart 2 (reading of force probe 2) significantly different from the force exerted by cart 2 on cart 1 (reading of force probe 1) during any part of the motion? Explain any differences you observe between your predictions and your observations.

In-lab Question 5: Explain how cart 2 is able to accelerate. Use Newton's second law and analyze the combined (net) force exerted by all the forces acting on it. Is there a non-zero net force?

Appendix II: Letter For Copyright Permission

June 7, 2001

Permissions Department
John Wiley & Sons, Inc.
605 Third Ave.
New York, NY 10158-0012

Dear Sir or Madam:

I am working as a part of a group of undergraduate students at WPI. We are adapting a Real Time Physics program for our university that will fit into fifty-minute lab periods. We would like to create photocopied laboratory handouts for approximately 25 students, on a one-time-use-only basis. We want to pilot test the shortened version of the labs. The six adapted 50-minute labs will consist of activities and questions selected from Labs 1-3, 5, 6, 8, and 9 in the book "Real Time Physics: Active Learning Laboratories" by David R. Sokoloff, Ronald K. Thornton, and Priscilla W. Laws (0471129658). We will be using approximately 50% of each of the following pages, p.1-82, 107-146, and 175-212.

In addition to the shortened versions, we will also be pilot testing the full labs from the book. To this end, we have purchased 25 copies of above-mentioned book. If the labs are successful, we will recommend that the Physics Dept. require that all students in future courses purchase the Real Time Physics book. Neither WPI nor we will receive any financial remuneration for the photocopied labs.

A duplicate copy of this letter and a self-addressed, stamped envelope is enclosed for your convenience in replying. If permission is granted, please sign and return one copy of the letter, indicating below how you would like the credit line to read.

Sincerely,

David Ramshaw
Worcester Polytechnic Institute

Credit line should read:

Appendix III: Student Attitude Survey

1) Did the labs contribute to your learning of physics? Explain.

2) Did the lab help you learn concepts that were relevant to the PH 1110 Lecture? Explain.

3) What could be done to improve the labs?

4) What did you like most about this lab course?

5) What did you like least about the lab course?

6) Would you have liked to have taken the normal labs instead of the computer based labs? Yes/No.