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# Physics Lab Toolbox - Collisions Lab

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# Physics Lab Toolbox 0907

## Collisions Lab IQP



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## Abstract

The goal of our IQP was to rejuvenate one physics labs in order to make it more enjoyable while maintaining the educational value. The introductory physics courses are very popular with the freshman students for a myriad of reasons. If these students have a negative experience with the introductory physics labs, they might be less inclined to take higher level courses, or they may stray away from majoring in physics altogether. Although the scope of our project was one lab, and we have no control of its deployment hereafter, we wanted to create a successful model and demi-template that could be easily followed and adapted for future labs.

We brought with us a fresh student perspective, many of us having already done these labs, enthusiasm, and general ideas of what a good lab should be. After sifting through countless existing labs, we got a strong sense that these labs were not constructed with the students' perspective in mind. We wanted to fully immerse ourselves in the minds of our target audience to create a lab they would enjoy reading and participating in.

In the end, we crafted versatile, sequential, and concise instructions that garnered favor with the students. We included setup images and Logger Pro Screenshots in the instructions to help ease student frustration, more clearly convey necessary messages, and cut down on the amount of words to read. We also created extra content panels that contained many of the potential problems the students could encounter in the lab, more detailed procedural steps, and explanatory physics concepts for the interested student.

In order to try and gauge the effectiveness of our new lab, we used a combination of qualitative and quantitative data collection and analysis techniques. In A term we used a combination of surveys and interviews to ascertain what the current student perspective was, in particular the aspects of the lab they had issues with. After that phase, we did our best to keep our lab consistent with the student feedback. After our lab was deployed, we administered surveys to two sections of classes that took our lab and two sections of students that took the old collisions lab.

Our survey results indicated that our instructions template and lab format was successful. There are many more aspects of student perceptions and physics labs that can be discovered and researched. We were only able to focus on a very small point in the vastly complicated web that comprises all the various aspects of student enjoyment and experience. It is our hope that the work we have completed in our IQP can be used to further benefit and improve the introductory physics curriculum.

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# Chapter 1

## Introduction

This IQP created a new Collisions Lab for the introductory physics course. We set out to improve the existing Collisions Lab, and in so doing provide an example that would be instructive for improving all the physics labs.

### 1.1 Choosing a Lab

At the outset of the IQP we were given the freedom to replace any lab in the physics curriculum with a new one. We decided on the collisions lab for PH1110 and PH1111 for a number of reasons. First, most of our group had taken PH1110 and so were familiar with the concepts involved in the Collisions Lab and had experienced the lab firsthand. Second, we judged this particular lab's instructions to be particularly subject to improvement. Third, we thought that the element of collision between two bodies would lend itself well to being made more enjoyable for students.

### 1.2 Lab Procedure

We intended to alter the existing lab's procedure, in order to make the experiment run more smoothly and enjoyably for students than before, and to exemplify the relevant physics concepts more clearly.

### 1.3 Lab Instructions

We intended to replace the existing lab's instructions with ones that provided additional benefits. We intended these new instructions to provide expandable extra content panels containing helpful material for students who were struggling, and descriptive images to make details of lab setup and software use more quickly grasped.

### 1.4 Roles of Group Members

Joshua Faucher and John Vilk worked on developing the new lab procedure and the use of Logger Pro. Joshua Faucher was responsible for the implementation of the new instruction format. John Vilk was responsible for drafting the initial instructions. Daniel Spitz and Jennifer Wunschel were responsible for data collection and analysis throughout the course of the project, and the application of the trends discovered during analysis to the lab. Each group member contributed to the final contents of the instructions, and wrote relevant sections of this report.

# Chapter 2

## Lab Procedure

When embarking on this IQP, we decided that we would be able to have students do more than one collision in our version of the lab if its procedure was clear. However, we had some apprehension concerning this, since every student we observed during A term took over one hour to perform the old lab, which only contained one collision. Our final version of the lab contained three. Thankfully, we were able to refine a procedure that students could complete within the one hour lab period.

### 2.1 Devising Three Collisions

From the start, we had three different collisions in mind. Initially, the first collision was identical to the old lab; the students would push a cart with two 500g weights into a cart without weights. The cart without weights had a force sensor attached to it to measure the impulse. Students would push the cart with weights into the cart with the force sensor, and record initial velocities, final velocities, and impulse.

However, this collision had one fatal flaw. Every force sensor is attached to the LabPro USB device by a wire. This wire drags when it is mounted on top of a moving cart, which adds significant error to the system. During the old lab, students would hold the wire in mid-air, but, during our tests, this caused an unacceptable amount of error in our momentum calculations. Even if we actively

## 2.2 Refining the Procedure

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tried to follow the cart down the track while holding the cord, it was visibly evident that the cord was dragging the cart.

Our solution was to make the force sensor stationary. We accomplished this by mounting it to metal poles that are mounted to the desk. Initially, we tried mounting it to the track, but the impulse generated moved the track itself. In any case, this reduced the amount of carts involved to one. Students would push the cart with two 500g masses into the stationary force sensor, and record impulse, initial velocity, and final velocity. When the collision is performed correctly, they should observe that initial velocity is nearly identical to final velocity.

The second collision involves a cart with two 500g weights, and a cart without weights. Students would push the cart without weights into the cart with weights, and observe that the final velocity of the weighted cart is dramatically smaller than the initial velocity of the cart without weights. Despite this, momentum is conserved. We did not use the force sensor during this collision, since we already established a relationship between impulse and change in momentum in the first collision.

We wanted to make the third collision an inelastic collision, and we experimented with a few ways to accomplish this. Our first attempt involved magnets stuck to the front of the carts. The magnets were too strong, and shifted around on the front of the carts when they collided. Our second attempt used Velcro, which worked very well. Every cart had the "hook" side on its left bumper, and the "loop" side on its right bumper. With this configuration, any two carts with Velcro can stick together.

## 2.2 Refining the Procedure

Once we had finalized the collisions, we needed to refine the procedure and identify possible problems that could disrupt students taking the lab. Our goal was to minimize percent error in momentum calculations to less than 10%. In order to do this, we had to make a few specific changes to the procedure.

The first collision, as mentioned in the previous section, involves a cart with two 500g weights colliding with a stationary force sensor that is mounted to a horizontal pole. This pole must be secured tightly to a vertical pole that is screwed

## 2.2 Refining the Procedure

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into the workbench at each workstation. If it is not on tight enough, the collision will cause the horizontal pole to rotate, which results in an inaccurate impulse reading. We decided that the TA's are responsible for checking this during lab setup. We also instructed the students to push the carts gently, in order to reduce the change of this occurring. In addition, the force sensor must hit the cart in the center of its base, or else the cart will go off of the track. We added this as a part of our lab setup instructions for the TA's. Also, each cart must be oriented so that the correct end hits the force sensor. Plunger carts have a plunger attached to a spring that absorbs energy, which throws off the impulse reading. Regular carts have a hole where the plunger should be, so the force sensor's sensing nub will fall into that groove instead of hitting the cart straight on. The other side of both types of carts had a flat surface at the base, which is needed for this collision. In order to simplify the way we communicate this to students, all carts had their Velcro pieces placed on the plunger or hole side, and students were instructed to conduct the collision with the Velcro facing away from the force sensor. Finally, we had an issue with the second position sensor interfering with the first one. Only one position sensor is required for this particular collision, but we had a second one plugged in to reduce the amount of time students spent setting up the next collision. This position sensor was facing the force sensor as well, so its sound waves were occasionally picked up by the other position sensor. To fix this, we instructed students to point the troublesome position sensor toward the ceiling. We decided to make this important procedure its own step, to ensure that students do not skim over it.

The second collision had fewer problems to solve. We had to instruct students to unplug the force sensor from the LabPro USB device after the first collision, due to Logger Pro problems documented in Section 2.3.2. Also, we had to prevent students from colliding carts with the plunger side facing inward, since their springs absorb energy and change the nature of the collision. Since all carts with plungers had Velcro on the plunger side, we simply instructed students to collide the carts with the Velcro facing outward.

The third collision was also fairly straightforward. As mentioned before, we placed the Velcro on the plunger side of plunger carts, and the hole- side of carts with holes in them. One may think that this was not a wise decision, since the

plunger side of carts interfered with the second collision. However, we discovered early on that the plunger side of the carts does not interfere with this inelastic collision. The Velcro latches before the plunger does anything serious to impact the energy in the system. For this collision, we instructed students to take the weights off of the cart with two 500g weights, turn the carts around so the Velcro faces inward, and then begin performing the collision.

## 2.3 Logger Pro Problems

Logger Pro is the computer program that the physics labs use to interact with various sensors. It is created by Vernier, the company that also manufactures the sensors. Since many students had trouble using Logger Pro in the old version of the collisions lab, we were determined to streamline the revised lab so that this does not occur again. By doing this, we discovered many undocumented behaviors in Logger Pro, and problems that could directly affect any physics lab conducted using this software.

### 2.3.1 Dropped Sensor Data

If a computer cannot keep up with data coming from sensors, Logger Pro will drop some of the data and throw off the graphs that the application displays. This behavior can be seen in Figure 2.1. We systematically replaced each component in our setup until we were able to determine that the computer was causing the issue. Switching our set up to a computer with comparable specifications had similar results; some data was dropped. When we collected data on a newer computer with better specifications, the problem stopped entirely. All of these computers far exceeded Logger Pro's system requirements. It is important to note that the problematic computers that we were initially using were used to perform lab experiments up until last year. Students conducting lab experiments this year will be using faster computers that we have verified our experiment on.

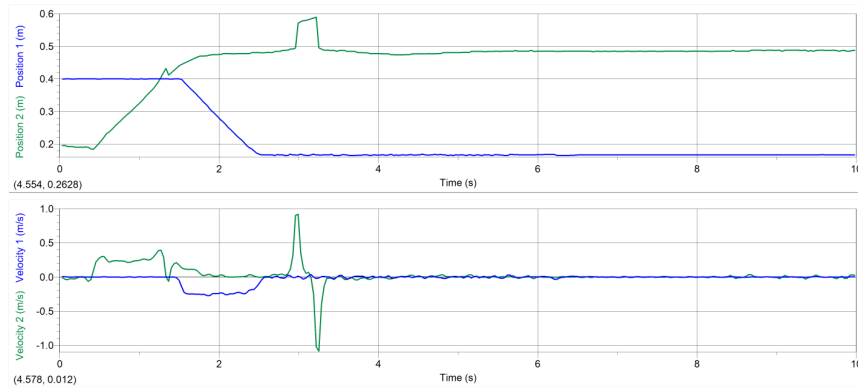


Figure 2.1: Dropped Sensor Information

### 2.3.2 LabPro Hardware Buffer Issue

On some configurations, the LabPro USB device cannot handle the amount of data that it is tasked with collecting. This can be actively demonstrated in the following procedure:

1. Connect two position sensors and a force sensor to the LabPro USB device.
2. Open our Logger Pro template.
3. Hit *Collect*. Note the rate at which the position sensors emit "clicking" noises.
4. Unplug the force sensor, and hit *Collect* again. You should notice that the position sensors are operating at a much faster rate.

Since the force sensor is tasked with collecting data at a very fast rate, the LabPro device cannot handle the additional overhead of collecting data from the position sensors. It results in a much slower rate than needed. It also affects the accuracy of the data; we have seen considerable interference appear on the position graph of the secondary position sensor that completely disappears in runs without the force sensor.

Lab designers should keep this in mind when designing future labs. While the LabPro device has seven ports for sensors, it cannot fully support a force sensor

and two position sensors at once. It is very possible that other labs are using a configuration of sensors that the LabPro device cannot keep up with.

### 2.3.3 Resizing Logger Pro

When most computer applications are resized, they dynamically redraw their interface to fit the new size. Some elements on screen may stay the same size, while others are shrunk. Logger Pro exhibits abnormal behavior when it is resized. While the toolbars and other menus at the top of the application remain the same size, the main part of the application that contains graphs and data tables does not. It shrinks to fit the new size, but does not dynamically redraw itself to fill up excess space. Instead, it adds black bars where needed to maintain the programs original aspect ratio, much like viewing a movie shot in widescreen on a standard 4:3 television. This can make some text unreadable, and make the interface difficult to use (see Figure 2.2). Many students may opt to resize Logger Pro so that the lab instructions can be placed to the left or right of the application, allowing them to view both Logger Pro and the instructions at the same time. These students will encounter this problem, and it could distract them from performing the lab as they search for a solution.

Fortunately, there is a workaround. Students can click on the *Page* menu at the top, and then on the *Use Entire Window* menu item. This will cause Logger Pro to redraw the lower interface so that it fills the entire screen. This must be done every time Logger Pro is resized.

### 2.3.4 Sensor Rate Issue

Logger Pro allows you to set the rate at which the sensors operate to fine-tune data granularity. In this lab, the force sensor must operate at a fast rate to measure the force of a cart hitting into it. This force is exerted over a brief time window, so a slower sampling rate may not pick up enough data points from which impulse can be measured. For this lab, we determined that the force sensor should operate at about 124 samples per second.

The position sensors operate at a much lower sampling rate. The maximum rate is 31 samples/second. We opted to use the maximum rate to ensure that



## 2.3 Logger Pro Problems

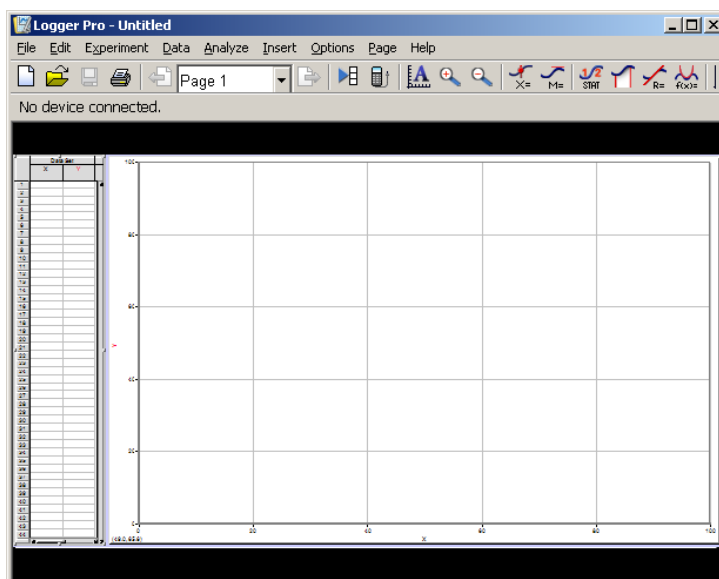


Figure 2.2: Black bars in Logger Pro.

plenty of data points are recorded, which should result in a less volatile velocity graph.

However, Logger Pro has only one field for sensor rate. This rate is applied in some manner to all of the sensors attached to the computer. This poses a serious problem, since the force sensor must operate at a much faster rate than the position sensors. Luckily, Logger Pro does not force the position sensors to collect data faster than their maximum rate. It uses an adjusted sampling rate, although the mechanics behind this adjustment are undocumented by Vernier.

We called Vernier seeking further information, but they had no answers to this problem. Since this is a major issue that could drastically alter our lab procedure, we reverse engineered the internal calculations that Logger Pro uses to determine the adjusted sampling rate to the following equation:

$$AdjustedSamplingRate = 10 + (SamplingRate \bmod MaxSensorSamplingRate)$$

This equation deviates slightly as the sampling rate increases, but it is a decent guideline for choosing an effective sampling rate for multiple sensors.

# Chapter 3

## Lab Instructions

From the beginning, we wanted to radically alter the presentation and content of our lab's instructions to make them more lively and easy to understand. The old lab instructions contained too many large blocks of text, which can intimidate students and cause an information overload. It also contained miscellaneous information interweaved with the actual lab procedure. In order to change this, we had to design a better way to present the instructions, write the instructions in a style that works with that design, and actually code the instructions as a webpage in order to present the instructions correctly. This chapter will explore these ideas in detail.

### 3.1 The Design

When we examined the old collisions experiment, we discovered many ways that the instructions could lead a student astray. The instructions consisted of seven bullet points, with a large paragraph at each bullet. When many of us took PH1110, we skimmed the instructions to find the important parts. This strategy, which we assume to be a common one, does not work well with these paragraphs. Important notes are scattered in separate bullet points and within paragraphs. These notes should be placed in line at appropriate places in the procedure.

The instructions are also not very clear about *what* data students should be collecting. This information is jumbled in a hodge-podge of miscellaneous information concerning *how* the data should be collected. If students employ the

skimming technique to only read the text that they feel is required to complete the lab, they could miss collecting important data.

Finally, the lab does not provide a separate data sheet for students to record their data. Instead, it combines the data sheet with the work sheet, which implies that students will be completing the work sheet during the lab period. Separating the data sheet from the work sheet, as mentioned in Section 2.1, allows students to complete the work sheet at their own pace outside of the lab, giving them more time to complete the actual experiment.

In our lab's instructions, we addressed these problems by presenting the instructions in a step-by-step style, placing important notes inside *Extra Content Panels*, clearly explaining the data that students should collect, and separating the data sheet from the work sheet.

### 3.1.1 Writing Style

We decided to make the language in the instructions simple to understand, informal, and short. The old collisions lab contained long sentences, and they could become confusing. Here's an example:

"The force sensor is mounted on one cart such that its force sensing probe will be struck by the other cart during the collision (and please check to see that the force probe sensitivity is set to the 50-N position)."

This sentence tells students to:

1. Mount the force sensor on one of the carts.
2. The force sensor should be in a position so that its force sensing probe will be struck by the other cart.
3. Set the force sensor sensitivity to 50N.

The first item can be interpreted incorrectly. Which cart should the student attach the force sensor to: the one with weights, or the one without weights? The second item doesn't provide specific information on how the force sensor is mounted. While this may be common sense to those that are familiar with the lab equipment, students may need a TA's help with interpreting this step, which

can cause them to wait a while if the TA's are busy. The third item does not tell the student where the sensitivity is set. Students may decide to look in Logger Pro for this setting, when it is actually a physical switch on the sensor itself. Also, the TA's are responsible for setting up the lab, so these steps should not need to be conducted by the students. Finally, this example sentence does not address the reader directly. In fact, it begins the sentence in the passive voice in order to avoid doing this. When appropriate, we address the students directly in a slightly informal manner. For example, near the end of collision one, we wrote "Now, you will need to collect six important pieces of information, and place them into your data sheet.", instead of "Six important pieces of information need to be collected, and placed into the data sheet."

Overall, many of the sentences in the old instructions can cause problems with the lab's flow. In our instructions, we assume that the TA's set up the lab correctly, and provide a setup image showing the students what their work area should look like for each collision. We also provide an image of where the sensitivity switch is on the force sensor, since the TA's can occasionally miss changing this. The alternative would be writing at least a paragraph explaining the setup in detail, which we assumed that most students would not read. And, since we discovered that mounting the force sensor to a cart caused too much error to be a useful experiment, we did not need to instruct the students on how to mount it.

### 3.1.2 Sequential Format

To make the experiment as clear as possible to students, we decided to break the experiment up into sections, and break each section into short numbered steps. If students follow all of the steps, they should have a relatively problem free lab experience. We endeavored to make the steps as short as possible to prevent the students from skimming them and missing important details.

Numbered steps also prevent students from getting lost in our instructions. Students can remember the step number they are on, look away to perform the step, and easily return to the instructions and find the next step in the experiment. If we used bullet points instead, students would need to scan the page for the

bullet point with the text that they read last. This problem is compounded in the old version of the lab, where each bullet point represents an entire paragraph of content that may contain multiple steps. The steps also do not contain any information that is tangential to completing the lab. Instead, we placed this information inside Extra Content Panels below certain steps. As previous physics students, we understand that some students like to complete labs quickly, and do not spend time reading content that they feel is not important. By doing this, students spend more time performing and observing collisions, and less time reading information that they are generally uninterested in. This gives students an opportunity to think about what they are observing in each collision, and more time to repeat collisions that did not complete successfully.

### 3.1.3 Extra Content

Before a typical physics lab begins, the TA will spend a few minutes giving the students an overview of the lab, the physics concepts conveyed in the lab, and common issues that the students may encounter. This takes away lab time that students could be spending completing the lab, and observing physics concepts first-hand. Not all students need this much help, and some students may not listen to the TA and ask questions later on topics already covered by this speech. Also in some lab instructions, such as the old collision lab instructions, important notes and tidbits are scattered throughout, which blends together essential information with optional notes.

To remedy this, we created *Extra Content Panels*. If a student needs help at a certain step, or if a student wants more information on the physics behind part of the experiment, he or she can click on a topic or question, and the instructions will display further information in-line. For example, when a student needs to measure impulse during Collision 1, he or she will need to zoom into the impulse graph in order to accurately select the "dip" in the graph. Doing this is less than intuitive; the student must click and drag a box that covers the entire area of the dip, and then zoom in. We placed an extra content panel at this step that clearly explains this, and contains images that illustrate good and bad zooms.

We aimed to help students with Logger Pro problems, physics concepts, and collecting useful data using these panels. Most were created to ensure a smooth lab session, since there are many small snags that are unrelated to physics that can frustrate and distract students.

### 3.1.4 Display

When looking at physics lab instructions, we noticed that many contained massive amounts of text that cluttered up the screen, which may cause students to skim through the instructions instead of reading them. As mentioned in the subsections above, we attacked this problem with extra content panels, and short numbered steps. Another important detail lies in how we displayed the instructions.

Our lab instructions are presented in an automatically resized web browser window that contains no toolbars or anything that that could distract students from reading the instructions. The window is placed to the left side of the screen so that students can easily resize Logger Pro and place it beside it, such that the instructions and Logger Pro are visible at the same time. The text size on our instructions is larger than normal, so it is easier to read. The background is gray for better text visibility, and the colors used elsewhere are pleasing to the eye without being too distracting or vivid. Also, the numbers at each step are slightly larger than regular text, which makes it easier for students to find their next step in the instructions.

Extra content panels slide down when students click on them to expose content inside. Clicking on them again reduces them down to a single sentence or phrase. Initially, the panels are in their single sentence phase, which presents the students with a clean look at only the essential instructions for completing the lab. This evades making the instructions look longer than they are, and cluttering the student's view with optional information and images.

### 3.1.5 TA Instructions

The TA instructions were the final component to our lab instructions. According to the TA's that we talked to, most labs only contain instructions for

the students, which they use to set up and teach the lab. We believe that the TA's require their own set of instructions for each lab that address their primary concerns: lab setup, common lab problems, and an overview of the lab flow.

While lab setup can be trivial in some cases, our lab became fairly complex as we identified possible issues and sources of error. This necessitated lab setup instructions that detail the initial setup of the lab to reduce, as much as possible, the amount of time that students spend at their lab station before colliding carts. These instructions should not be placed into the instructions that students see, as in the old collision lab's instructions. That would require students to read through it before getting to the part of the lab that concerns them. Instead, we placed this information as the first section of the TA instructions.

When we were running trials of the lab, we discovered a number of possible issues that could be addressed by the TA's. We placed all of this information into the TA instructions as an individual section that the TA's could quickly reference when a student encounters an issue. This can increase TA productivity, as TA's will spend less time troubleshooting identified issues with students, and more time ensuring that all of the students are on track.

Finally, we included an overview of the lab experiment in the TA instructions. This allows the TA's to quickly learn the flow of the lab, and understand the procedure students will be following at a high level. This was much shorter than the instructions that the students were viewing, since the TA's are already well versed in Logger Pro, physics, and the lab equipment. This section also contained images of each collision setup, which help communicate the differences between each phase of our lab.

## 3.2 The Code

The code for our instructions were developed utilizing two main languages with the assistance of a third minor language. Hypertext Markup Language, which shall henceforth be referred to as HTML, was used to form the basis of the instructions template. JavaScript was used to augment the HTML template, and drive the dynamic features of our instruction set. The style of the instruction template was defined using several Cascading Style Sheets, which will be referred

to as CSS. The instruction set is contained in a single HTML file *lab.html* which references the CSS and JavaScript files mentioned previously.

All of the code in our instructions template was written using a style which would allow someone who was not familiar with the instructions to easily read and understand what each element of code is supposed to do. From the beginning, the HTML code was properly indented, allowing people to see a hierarchy and supporting ease of understanding. Our HTML code makes use of a simple hierarchy of containers. Each section of the instructions resides inside of an HTML *div* tag, which is assigned the class *curveyRedraw*. This class corresponds to a style in the *instructions.css* file and creates the appearance of the individual instruction sets. Because the layout and style of each instruction set is identical, we are able to write one style and apply it to each instruction set. Each instruction set is identified by a unique id tag so that one can easily scan for the section of the HTML they want to edit.

The hidden content panels in our instructions are made up of two *div* tags; one of the tags, which is of the class *supplementary* contains the title of the panel as well as the second *div* tag. The second *div* tag is of the class *hidden* and contains the content that is to be hidden. In order for the extra content panels to function in the manner we decided upon during the development phase of our project, our team had to develop a JavaScript function which would read in the id of the *div* tag to be shown or hidden, determine the current state of that particular *div* tag, and toggle the style applied to it to either *block* or *none*. In order to change these styles, the JavaScript changes the actual CSS style applied to the individual *div* tag.

In addition to the extra content panels, our team desired the ability to embed instructional videos into the instructions. Due to the immense amount of time involved in developing a standalone flash video player for embedding videos into a webpage, we opted to utilize an open source flash video player. We elected to use JW Player 5, which is released under the Creative Commons Attribution-Noncommercial-Share Alike 3.0 Unported license. We chose this player because it was not only light-weight but also easy to integrate into our existing code.



### 3.2.1 Limitations of Sharepoint

Our team was bound to the constraints of the Microsoft Sharepoint environment which the Physics department uses to make labs and other information available to the students in the physics classes. This environment limited the languages we could use in the development of our instructions to HTML, CSS, and JavaScript as we would not be able to access a server which could interpret other high level web development languages such as PHP or Perl. Sharepoint also forces a user to check in each individual file stored in the documents folder for a particular page. This made deploying our lab instructions a little more difficult than deploying a traditional set of lab instructions would have been. The added difficulty is due to the fact that we developed the lab instructions following a generally accepted file structure system where different file types are stored in different folders. For example, the actual instructions HTML file is stored in the root folder of the Sharepoint site and the images used in the HTML file are stored in a directory in the root folder called images. After uploading our instructions, we had to open each directory and make sure that each file was checked in, otherwise the instructions page would not display properly.

### 3.2.2 The Coding Process

Developing the code which is responsible for displaying our instructions and driving the features we incorporated into the instructions was a relatively long and straight forward process. Most of the development went smoothly and the HTML was written without running into any major snags. All of the delays in the coding process were related to the JavaScript which drives the dynamic portions of our instruction set as well as browser compatibility.

# Chapter 4

## Data Collection and Analysis

During the course of our IQP, we used a few methods of data collection and analysis to gauge the student experience. In A Term, we used qualitative methods to explore the key factors affecting student experiences in physics labs. We issued surveys to two lab sections and conducted numerous interviews, all in the hopes of getting a better feel for the aspects of the labs that were working out, and the ones that were not. During B Term we analyzed the surveys briefly, and performed an in-depth analysis of the interviews. By the end of B Term, we had identified a set of key issues that seemed to cause the most common problems with physics labs. In C Term, we used quantitative methods to gauge the effectiveness of our lab in terms of those issues identified during B Term. We administered a survey targeting these issues to students in sections that took our lab, and sections that did not, and used the results to compare the two groups, and evaluate the effectiveness of our lab.

### 4.1 Designing and Deploying A Term Survey and Interviews

Upon beginning our IQP, we were armed with our own experiences with physics labs and some intuitions about what might improve them. To get a more complete understanding of what we might do to improve a lab, we sought out advice from Professors Koleci, Keil, and Gao, and Fred Hutson. We de-

## 4.2 Analysis Process and Reactions to A Term Data

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signed a survey and set of interview questions based on their feedback and our aforementioned intuitions.

The survey and interviews asked general questions regarding instruction clarity, level of enjoyment, interest in physics, and understanding of the concepts of conservation of momentum in a collision and Newton's Third Law. We kept the surveys brief and administered them to all the students during the lab. We collected the responses as students left. This method yielded a very high response rate, with very few students not completing a survey. It seems likely that conducting an online survey after the lab would have received a much lower response rate, given our own experience with online surveys. After collecting the responses, we entered the answers by hand into an Excel spreadsheet.

As an incentive for students participating in an interview, we held a raffle for a \$100 gift card from amazon.com. This method received a surprisingly high response rate, with about 55 percent of students in the sections we observed participating in an interview. The interviews were conducted between one student and one member of our team, either Dan Spitz or Jenn Wunschel. Each interview lasted about two minutes. The interview style was not very in depth, with the same set of questions being asked each time. The interviews were recorded on small audio recorders, and the recordings were transcribed to text afterwards.

## 4.2 Analysis Process and Reactions to A Term Data

After collecting survey responses and interview recordings, we made an effort over B Term to analyze the data, identify some new issues with the lab, and to confirm or refute our own intuitions about what should change. We attempted to identify statistical patterns and trends in the survey responses, which unfortunately proved fruitless. We were able to perform an in-depth analysis on the interviews, and ultimately got the information we wanted and needed.

To analyze the survey data, we used the software SPSS. We generated charts showing the distributions of responses for each survey question. We also looked at charts showing joint distributions of two questions at once, to identify any

## 4.2 Analysis Process and Reactions to A Term Data

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correlations. Our first reactions were ones of surprise. Students tended to answer questions more positively than we had expected them to. Although students tended not to enjoy the lab particularly, their responses regarding clarity of lab instructions rated the lab decently, even though we had selected the collisions lab initially as having particularly unclear instructions. Our expectations had been for students to rate the instructions as unclear. Our attempts at identifying correlations between variables were unsuccessful, and we found no useful or pronounced correlations.

Our initial attempts at analyzing the interviews yielded similar results. Students seemed to regard the lab as acceptable, and similar to past labs they had participated in. It was upon coming in contact with Professor Zastavker that we began receiving the necessary guidance that let us dig deeper. We came to the realization that there had been flaws in our composition of survey and interview questions and interview techniques. These flaws caused our results from both the surveys and interviews to be vague, overly general, and in some cases incorrect. Our questions were often not specific enough, or used a term, such as "enjoy", that had different meanings for different students in the context of physics labs.

Despite the fact that we had not made such considerations while designing or administering the interviews, we were still able to use the interview transcripts to effectively discover trends and common issues. We used a method called *coding* to identify the common themes present in the speech of the students. Coding consisted of developing a *code book* containing a list of the themes, or *codes*, we had developed as we progressed through the interviews. As we came across codes that already appeared in our code book we highlighted those passages in the interview transcript with a color corresponding to that code. In this way, we were able to break down each interview into segments of commentary on particular codes. As we coded more of the interviews, a picture of the actual perceptions of the students began to emerge. We realized that the likely reason for the relatively accepting attitude of students was that they had not considered how much labs might really be improved. We identified the main reasons for frustration students felt, although often this frustration was masked by self-blame or complacency.

By the end of our analysis over B Term, we had a small set of issues that seemed to be the main source of problems for students during labs. These issues,

## 4.2 Analysis Process and Reactions to A Term Data

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along with our proposed solutions, were documented in the following report:

### 4.2.1 Themes Report

**Confusion with Logger Pro software** Several students expressed sentiments of frustration with using the Logger Pro software. Students found it difficult to use the software in the way that the lab called for. Some students even believed that Logger Pro does not work properly, though this is likely due to misunderstanding on the part of those students. What is clearly present is poor familiarity with the software. This can be addressed in the instructions by using screenshots of Logger Pro and describing the tasks to be performed in terms of using the software.

**Frustration With Multiple Trials** Several students expressed frustration over the need to conduct multiple trials in order to get useable data for the lab. Part of this issue can be addressed by altering the setup of the experiment in order to minimize unreliable aspects of it. However, imperfection in the lab setting is an unavoidable part of experiments, and cannot (and should not) be eliminated completely. What ought to be addressed is the attitude of frustration that many students feel when things do not work on the first several trials. This can be alleviated by having the instructions address potential problems with setting up the experiment and running it. Mentioning possible snags in the instructions will better shape students expectations. Students will not be as frustrated if they do not expect the experiment to run perfectly the first time, and have some guidelines to help them address errors if and when they come up.

**Aversion To Asking For Help** In several interviews, students expressed an aversion to asking for help from the TA's. The instructions can address this issue by both clarifying some points, and by mentioning which situations might warrant asking for help. This may help change the expectations of students such that they are not averse to asking TA's for help.

**Difficulty Applying Concepts** Some students said they were confused when trying to apply physics concepts to the lab. This is a particularly important issue, given that one of the main purposes of the labs is to demonstrate physics concepts in the real world. Some of the misunderstanding cannot be helped, since it is the

### 4.3 Designing and Deploying C Term Survey

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responsibility of the students to properly familiarize themselves with the concepts. But the lab instructions can also be made to function as a useful educational tool, providing information about the physics concepts behind the experiment at hand.

### 4.3 Designing and Deploying C Term Survey

In order to gauge how effective our lab was, we designed a new survey to be deployed to students who participated in our lab, and ones who participated in the older collisions lab. The survey was significantly longer than our A Term survey, and we took steps to avoid the flaws that had made our previous survey ineffective. Given that the nature of our data collection in C Term was quantitative, and meant to evaluate our lab against a set of criteria already determined, we elected not to conduct interviews, which were more appropriate for qualitative measures. The survey's intent was threefold. First, it would measure the effectiveness of our lab based on the set of issues determined during B Term. Second, it would gauge student opinion of various particular features of our lab instructions, including setup photos, Logger Pro screenshots, extra content panels, and the step-by-step instruction format. Third, it would identify possible confounding factors that might affect the results, including student comfort with his or her section's particular TA's and the student's opinion of his or her lab partner's knowledge level.

The survey was administered to two sections that took our lab, and two that took the old lab. For each of the two days of our lab's deployment, one pair of TA's would administer both the old lab and the new one, in an attempt to mitigate the confounding factor of student comfort with TA's. Our entire group also acted as extra TA's for both the old and new labs to make sure things ran smoothly for the students. A slightly abridged survey was administered to the students that took the old lab, since questions regarding the particular features of the new lab would be irrelevant to them. Like with our A Term survey, we had a very high response rate via the method of administering the survey during the lab and collecting the responses at the end. Upon completion of all four of the labs, we again entered the results into an excel spreadsheet.

### 4.4 Analysis Process for C Term Survey

To analyze the results from the surveys, we performed a comparative analysis of the distributions of answers to survey questions from the old and new labs. We looked at charts of these distributions, created in excel, and also looked at the means and standard deviations of the distributions, calculated using an analyzer program we wrote. We used these methods to help ourselves quickly identify the patterns and trends in the data.

### 4.5 Reactions and Conclusions to C Term Data

Our Reactions section comprises our experience observing our lab's deployment. It is the culmination of all we were able to observe, and our inclinations about our success based on those observations. The Conclusions section provides clear evidence from our surveys of our triumphs and the student's perception of our lab.

#### 4.5.1 Initial Reactions

Through our hard work and efforts detailed in previous sections, we were able to deploy the lab we had spent so much time designing. We observed the old collisions lab, followed by our own. During our lab, we were relieved at how smoothly the process executed. Major themes and trends we observed were that the students used our images as we intended, they used the extra content panels prior to asking for help, the kinds of questions asked were more simple in nature than those in the old lab, and they were able to complete the lab faster. The trends mentioned were observed in both of the sections that took our lab, despite that the personality of each of the sections was very distinct.

The students seemed to refer to our setup images and Logger Pro screenshots often during our lab. Rather than raising their hands and asking where a button was, they were able to locate it on their own. They also utilized our collision setup images heavily. Despite having three different collisions, the students had no trouble shifting through each phase of the lab. The first section that took our

## 4.5 Reactions and Conclusions to C Term Data

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lab tended to rush and paid little attention to much of our written instructions, yet there were not any major transitional problems for that section. Our instructions seemed to work well with two distinct types of students: the student that wants to finish as fast as possible, and the student that is more patient and is willing to read all the directions.

We were able to observe true utilization of our extra content panels in both sections. This intercepted many of the questions that were asked in the old lab. We hoped that the extra content panels would encourage students to be more proactive in their lab experience, rather than rely on a TA or instructor telling them what to click next. There were students that asked questions that were clearly addressed in our extra content, but in general, the number of those kinds of questions was greatly reduced.

Not only did the students make use of the tools we provided them, the kinds of questions they asked during our lab were much simpler and more informed than the questions asked in the old lab. In the old lab the questions were often vague, and reflected that the student was unsure of what to do at all. They seemed to experience confusion about multiple parts of the lab all at one time. This made answering their questions more of a challenge. During our lab, there was a distinct difference in that the questions were direct and specific. It clearly demonstrated to the TA's that the students were on the right path, but had a simple clarifying question to help them reach the end goal. Consequently, their questions were much easier to answer. The students seemed more satisfied by these answers; they were not asking for someone to complete the process for them. Rather, they were confirming that their methodology was accurate.

A concern prior to lab deployment was the length of our instructions. In the collisions lab we observed in A term, it took all of the sections more than the allotted 50 minute time period to complete one collision. We had created three collisions, and our instructions were much longer. It was our belief that because our instructions were plainly stated and logically organized, that the students would have enough time to complete the lab in the 50 minute period. The students were able to complete the old lab in C term in approximately 40-50 minutes. However, they were able to complete our lab in approximately 30-35 minutes. In both cases, there were lone stragglers that did take longer, but these



## 4.5 Reactions and Conclusions to C Term Data

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estimates are based on how long it took the majority of students to finish. Despite a longer lab with more content and information to digest, the students were able to complete our lab in less time.

After observing our lab deployment, we were very hopeful about our survey results. There were not any large problems that arose, and we had several students approach us after our lab thanking us and complimenting the lab. It was a promising start to the conclusion of our IQP.

### 4.5.2 Conclusions

After analyzing our survey results, we discovered that the students responded more favorably to our lab than the old collisions lab. Our goals were to create a more enjoyable lab by creating a step-by-step instruction format that utilized images to augment the written direction, minimize confusion with Logger Pro, and deliberately reinforce concepts from lecture and conference to make the content feel more relevant to the students.

The entire purpose of our lab was to better the experience of each student. We learned from our experience in A term that what a student defines as fun or enjoyable is extremely complicated. We tried to address some of the components that we felt are integral to lab enjoyment. Before any in depth analysis into the outcome of our particular approaches and methods are discussed, we determined as shown in 4.1 that we created a more enjoyable lab overall.

We asked the students how much they enjoyed the lab twice: at the beginning of the survey, and at the end. We felt that their initial reaction to the lab and their perception after considering the lab in detail would differ. This turned out to be quite true. When the two graphs in 4.1 are compared, our lab is rated to be more enjoyable in both cases. As expected, after the students considered specific elements of the labs, there was a shift in their answers. The second time the students that took our lab answered the enjoyment question, they tended to answer that they enjoyed it more. There is a clear shift in the graph to the left in the positive direction. Conversely, there is a shift to the middle and slight right for the old lab. After some thought, the students seemed to find the old lab worse than their first reactions.

## 4.5 Reactions and Conclusions to C Term Data

Due to our discovery in A term, that students did not really know or think about how a lab could be, or what components comprise a lab, we anticipated a shift in the results. We reasoned that if we asked them to think critically about the lab, rather than think of a general impression, it might change their perception. There were some comments on our surveys where students indicated that, "Labs are never fun". We hope that this shows that labs can be educational and enjoyable.

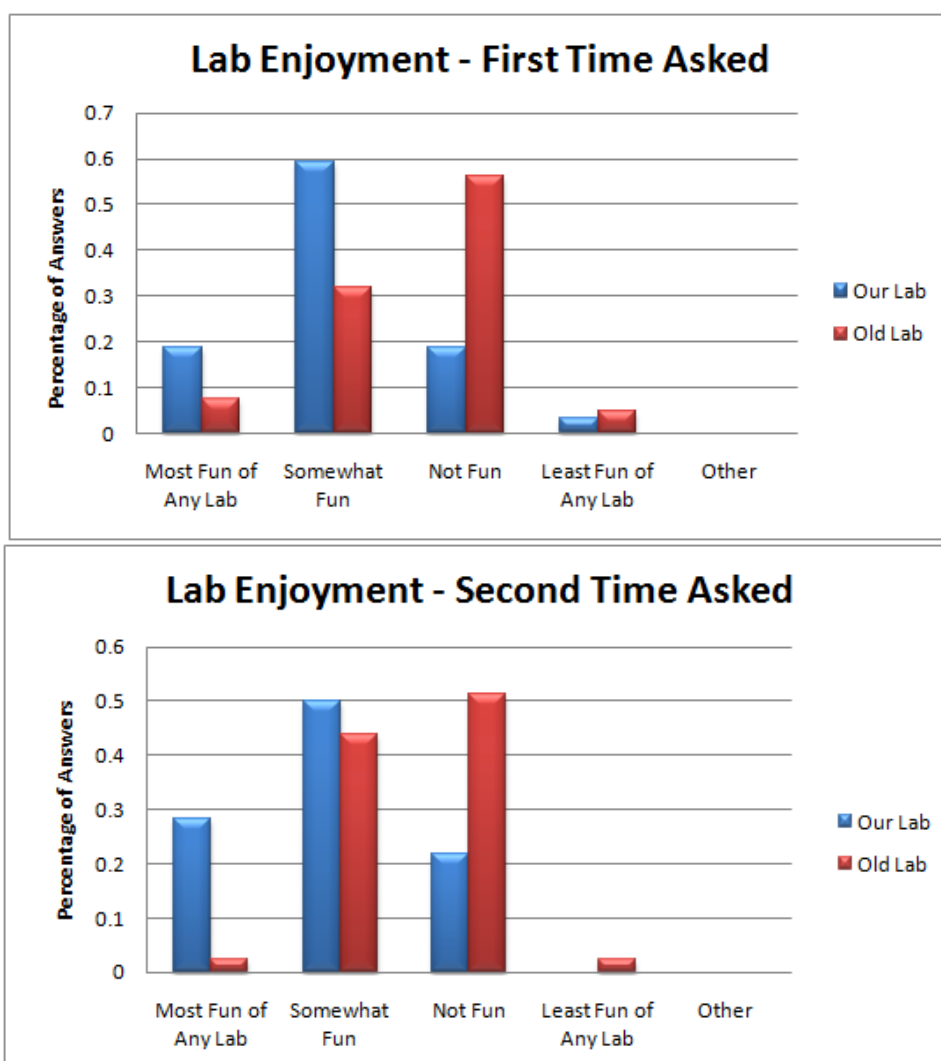


Figure 4.1: Lab Enjoyment

## 4.5 Reactions and Conclusions to C Term Data

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As previously stated, we felt that by improving on specific aspects of the lab, we could increase the students' enjoyment of it. The instructions for the old collision's lab was in a paragraph format and was poorly organized. We hypothesized that providing sequential instructions, that is numbered step-by-step instructions in a procedural format, it would make the lab easier to follow. This would allow students to take their time and perform the experiments at their own pace, without having to digest an entire paragraph containing a myriad of unrelated information. As shown in 4.2, the students strongly preferred our instruction format to the format they encountered in previous labs.

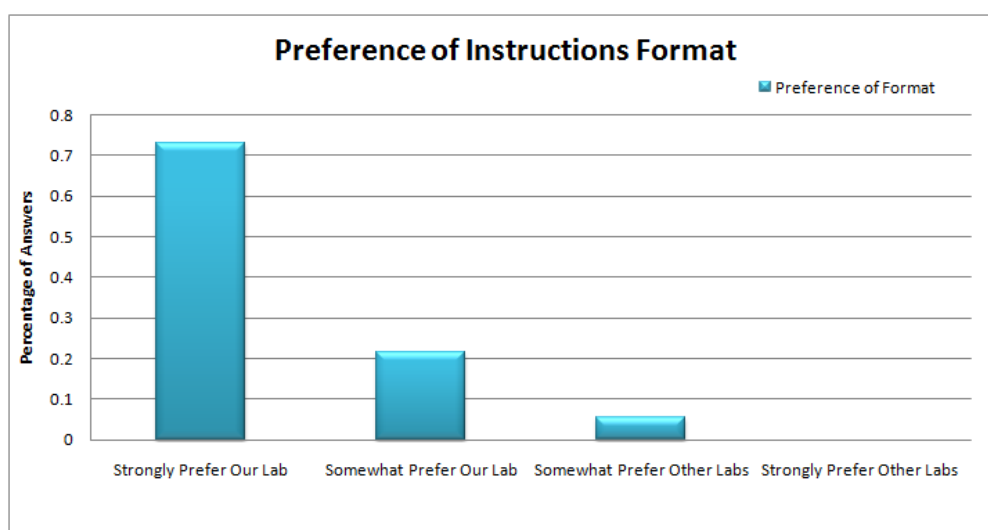


Figure 4.2: Preference of Instruction Format

Students also responded very positively to our many images depicting the setup of each of the collisions. We wanted to take images that were clear, and that showed an accurate representation of each collision. In the previous lab, there was a single image from only one angle. As demonstrated in 4.3, most of the students found our setup images to be "Very Frequently" to "Somewhat Frequently" helpful, with most students selecting the former.

To supplement our sequential instructions, we also wanted to provide extra content that would explain in more detail some physics concepts and address problems or aspects of the lab itself. We felt that using these panels would allow

## 4.5 Reactions and Conclusions to C Term Data

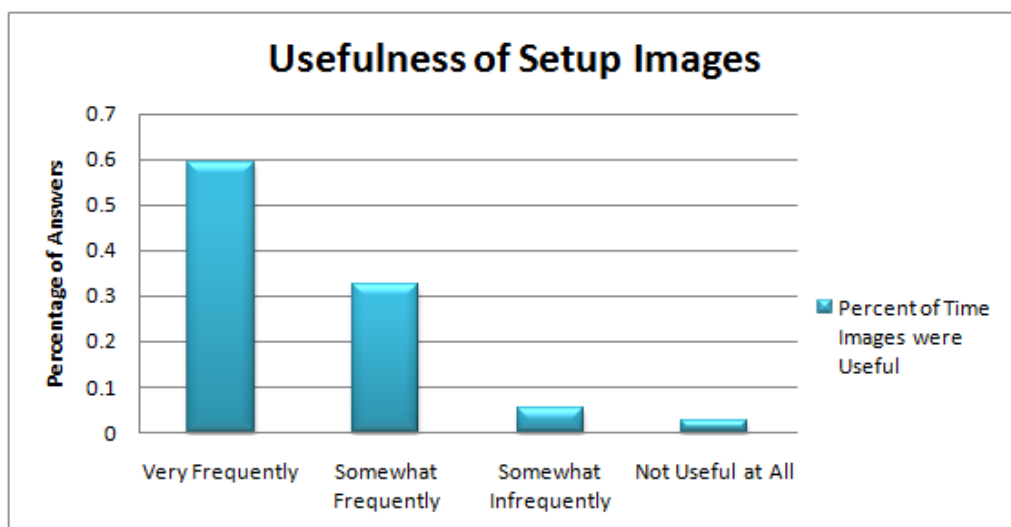


Figure 4.3: Usefulness of Setup Images

the students to only read the material that they deemed necessary to succeed in the lab. The students responded very positively to our extra content, 4.4. They overwhelmingly found them to be highly useful.

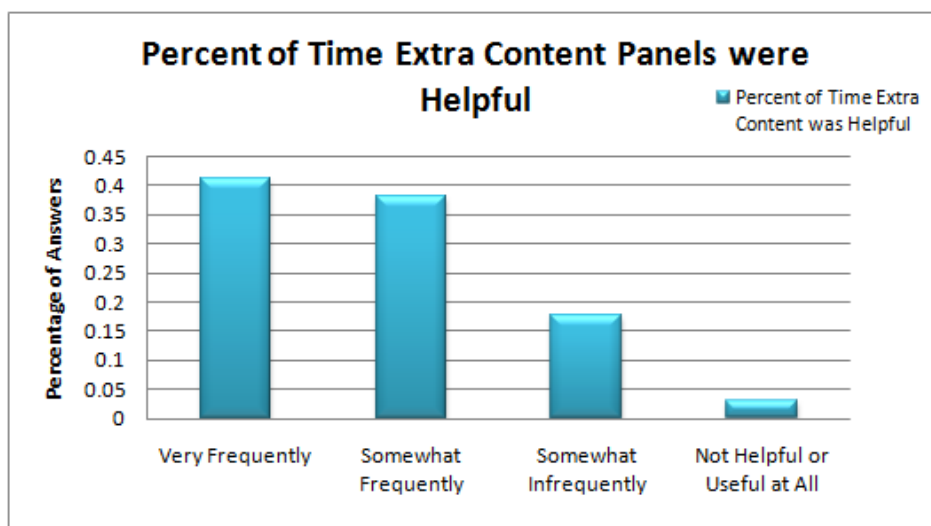


Figure 4.4: Usefulness of Setup Images

In addition to streamlining our procedure and instructions, we wanted to

## 4.5 Reactions and Conclusions to C Term Data

make the process of using Logger Pro as straightforward as possible. We felt that the students should not have hesitations or concerns about using the software, since it detracts from the lessons of the lab. During our observations in A term, the students seemed unfamiliar with common functions of Logger Pro. We were surprised upon data analysis, that they did not rate Logger Pro to be confusing on the surveys. We found a similar pattern with Logger Pro in C term. Despite this, in 4.5 students rated Logger Pro more straightforward to use in our lab than in the old lab.

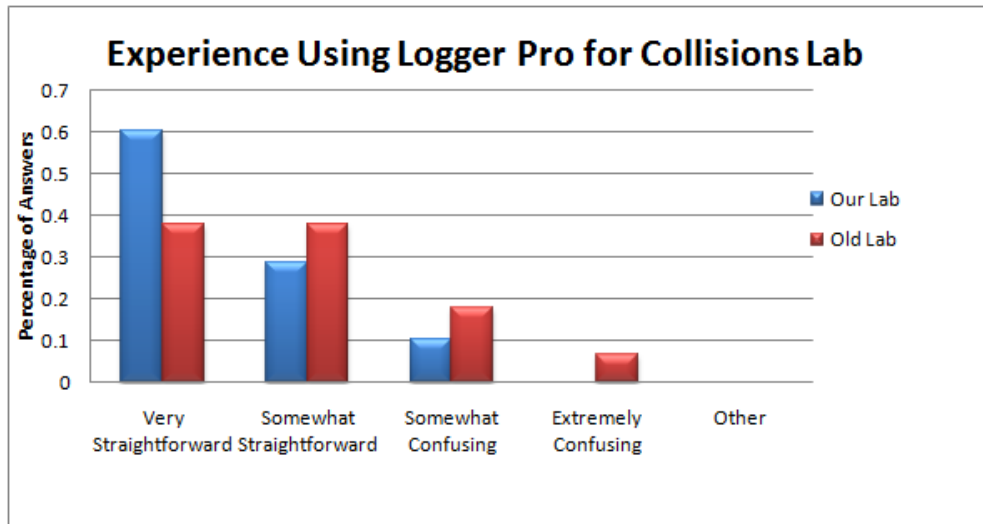


Figure 4.5: Experience Using Logger Pro for Both Collisions Labs

We also found that generally, that the experience of the students that took the old lab to the past experiences of the students taking our lab was similar 4.6. This simply demonstrates that one section of students were not a great deal more familiar with Logger Pro than the others.

Perhaps the most important distinction is the one made by total Logger Pro experience of the students' who took our lab. They felt that Logger Pro was more straightforward in our lab than in the other labs they had taken. They benefitted from instructions that included how to use the software, and they felt it increased its usability 4.7.

## 4.5 Reactions and Conclusions to C Term Data

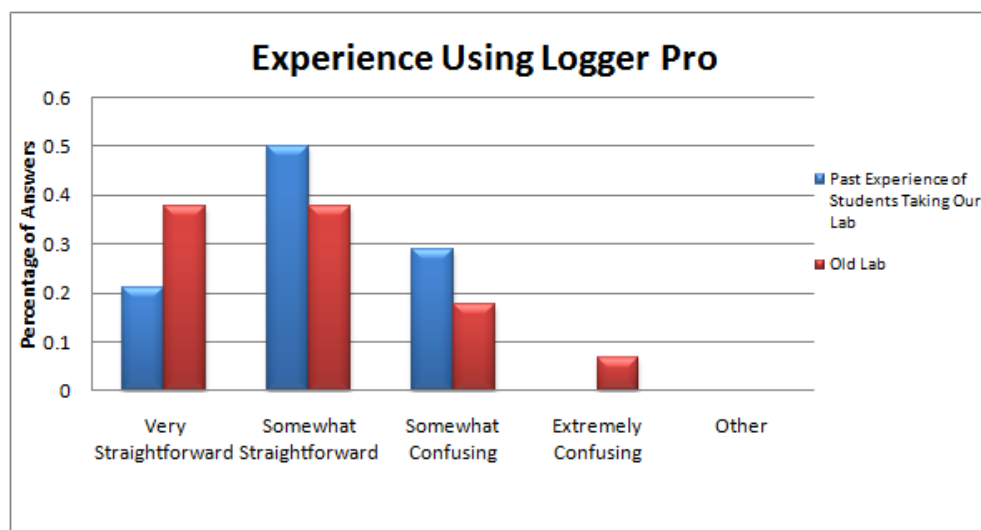


Figure 4.6: Experience Using Logger Pro for the Old Labs and Prior Labs

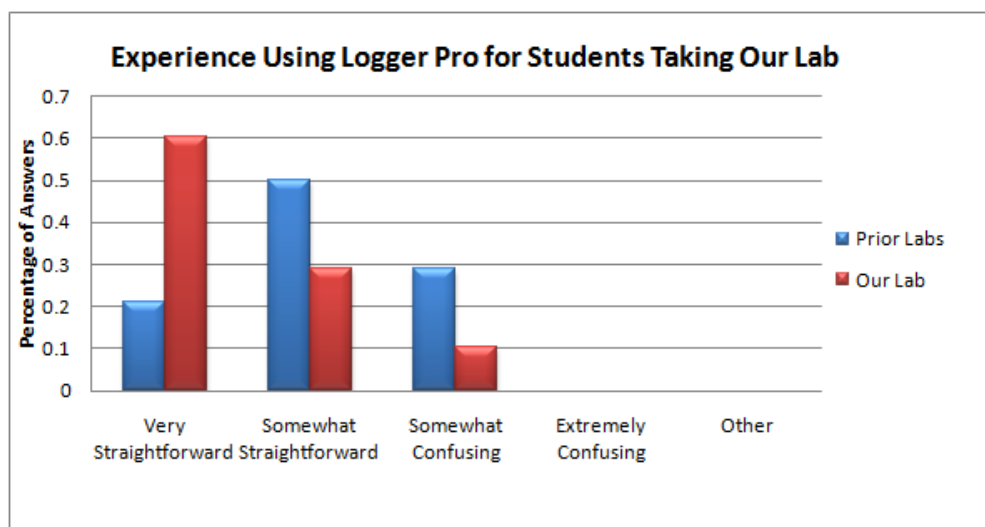


Figure 4.7: Experience of Logger Pro for Students Taking Our Lab

In order to account for the possibility that the students found Logger Pro more straightforward to use for our lab because it occurred later in the term, and they had used previous labs to become familiar, we specifically asked them if they found our Logger Pro screenshots helpful. As shown in 4.8, they clearly did.

## 4.5 Reactions and Conclusions to C Term Data

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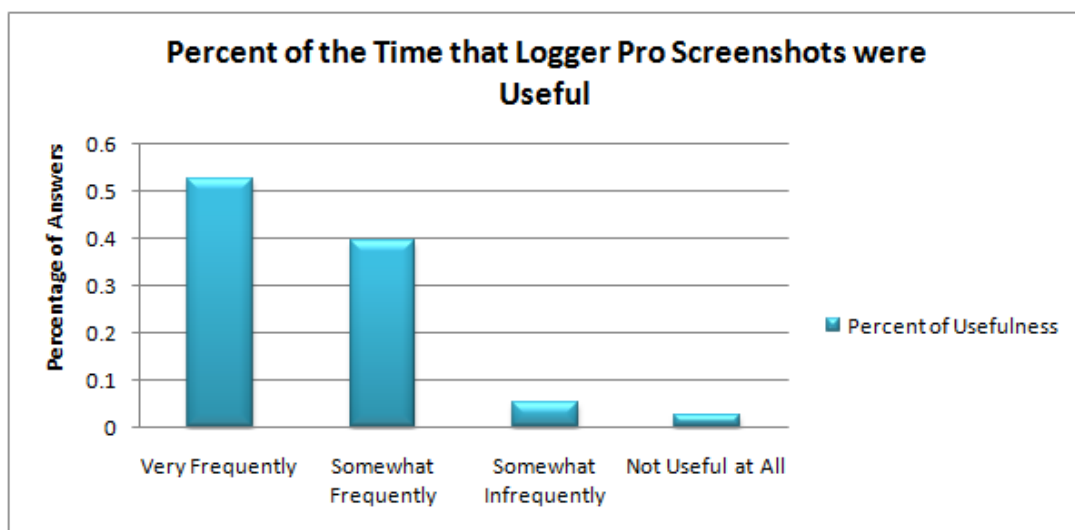


Figure 4.8: Percentage of the Time that Logger Pro Screenshots were Helpful

We also wanted to focus on making the material in the lab reinforce the concepts from lecture and conference. Being WPI students ourselves, we often understand the frustration of feeling as though things learned in lectures will not be useful later in our careers or lives. Often, students might not realize that concepts are being reinforced unless it is overtly stated. This was something lacking in the old lab, and rather than leaving the students to make the connection on their own, we pointed out the connections to the various principles being demonstrated. We were pleased that all of the students had the material covered prior to the lab, 4.9. Note the answers are nearly identical for both groups of students.

The results of concept reinforcement were radically different, 4.10. We received overwhelming positive feedback on our lab's concept reinforcement, whereas the old lab was rated quite poorly in this area. Both labs do demonstrate concepts, but what is important is that the students are able to make the connections.

We accomplished our goals of improving the collisions lab. We took a great attention to detail about what comprises a lab. We were not only able to create a more enjoyable lab, we were able to increase the quality of each component of

## 4.5 Reactions and Conclusions to C Term Data

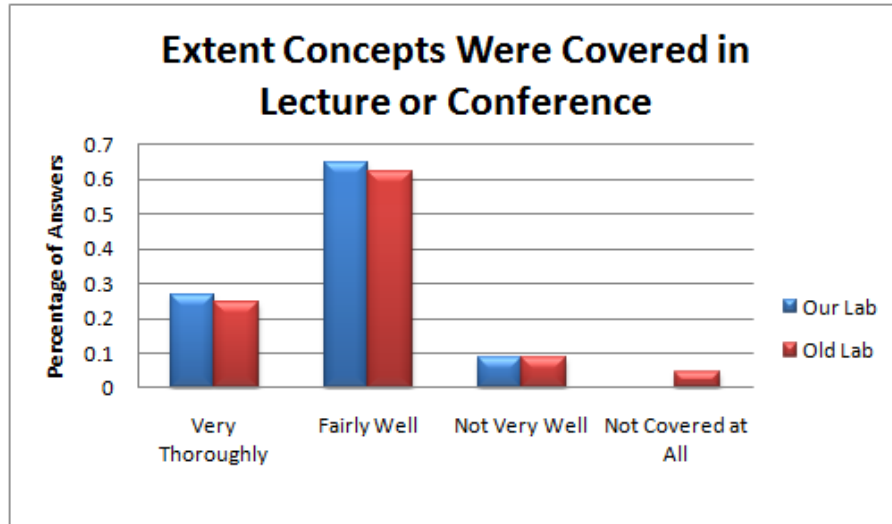


Figure 4.9: Extent that Concepts were Covered in Lecture and Conference

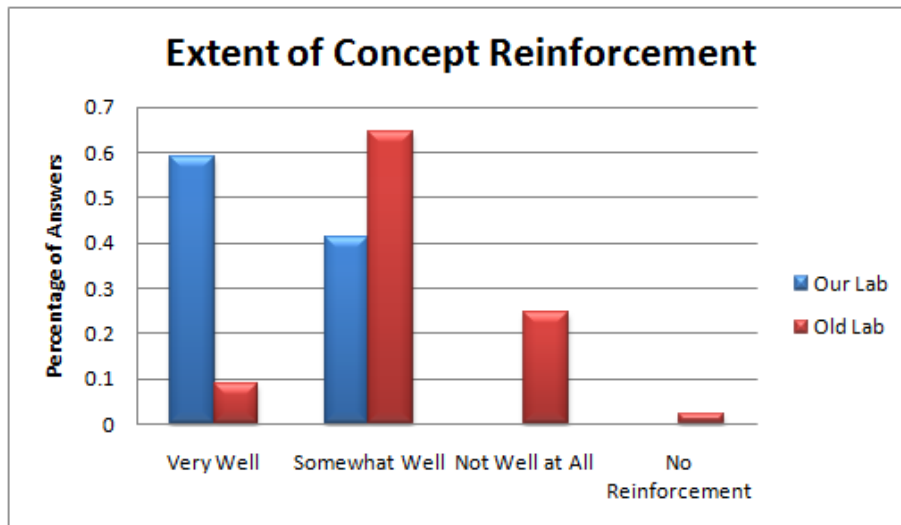


Figure 4.10: Extent that Concept Reinforcement

the lab.



### 4.6 Uncontrollable Conditions and Future Research

Unfortunately, we could not control every aspect of the labs. The students involved and any other human aspect in the lab can greatly affect analysis results. The two major factors that might have affected our lab that was beyond our realm of control were the lab partner experiences and the TA's.

We were unable to find any meaningful correlation between the knowledge of each partner, their ability to work together, and the overall lab enjoyment. This may be due to the fact that our lab was very clearly laid out, resulting in less of a need for partners to try and work out difficult problems together. However, we cannot really be sure. It would be very interesting to delve deeper to try and determine if partners can dramatically affect the lab experience.

In an attempt to make sure a poor experience with a TA would not skew our results, we asked questions in our survey about how the student felt interacting with their TA. First, we wanted to establish how comfortable the students felt asking the TA's for assistance, 4.11. The students felt more comfortable asking for help in our lab. They also felt that their questions were more clearly answered in our lab as shown in 4.12. These results may be due to the fact that in our lab, the students were more comfortable asking questions because they had specific questions to ask. It may also be attributable to the fact that since in our lab the questions were more direct, they were more easily and fully answered by the TAs. Other than conjectures, we cannot say definitively what the cause was for this discrepancy.

We were able to review the grades of the students, without their names, for all of the labs they had taken and completed worksheets for. We were unable to find any sort of correlation between the grades and our lab. The grades did not seem much better or worse than the grades from other labs, or the old collisions lab. It might be highly beneficial to look into measuring how to make a lab more educational.

## 4.6 Uncontrollable Conditions and Future Research

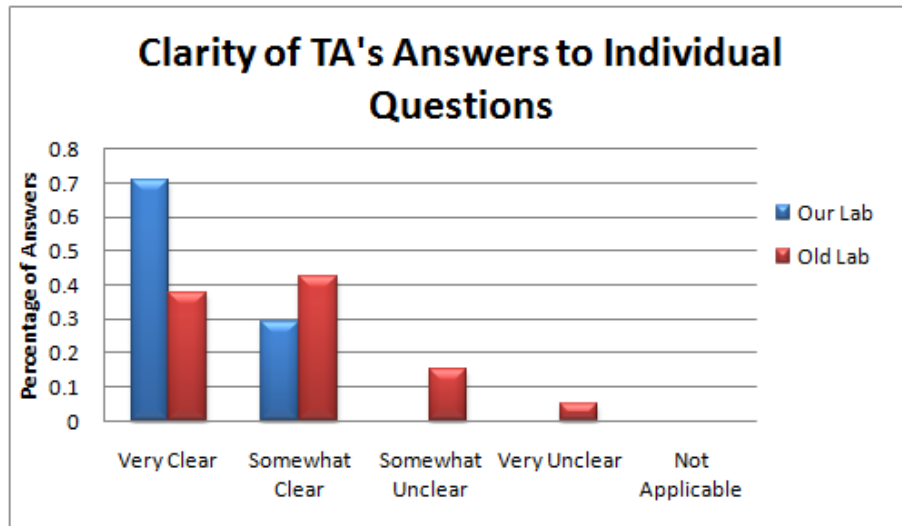


Figure 4.11: Students' Comfort Level with the TA's

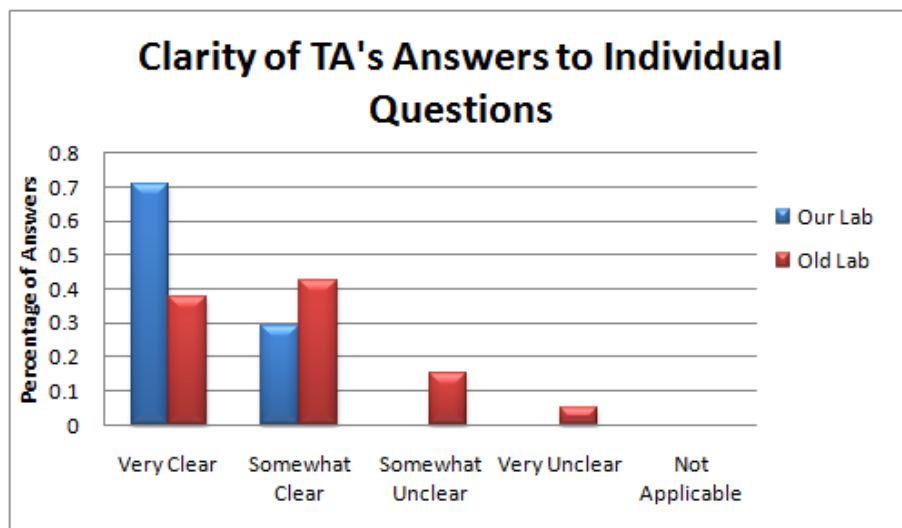


Figure 4.12: Student's Perception of the Ability of the TA's to Answer Individual Questions

### 4.7 Advice and Recommendations for Future IQP Teams

We have learned a great deal throughout this IQP that can be very useful to future teams. If the IQP is regarding students, it is paramount that the team put themselves in the students' shoes. Despite how clear or obvious something may seem, if the students cannot perceive it as clear, nothing meaningful will be accomplished. As discouraging or pessimistic as it might seem, most students want to put forth the least amount of effort required to get through a class. Knowing this, try and make the content interesting or relevant to them. We all know what it is like to be a student, if you would not enjoy something in a class or lab, we encourage you to really consider why. Chances are if you react negatively to it, they will too. Even though this might seem like common sense, it truly is not as easy as it seems.

We recommend that the next team really focus to see if TA's or partners play a major factor in lab enjoyment. Unfortunately, we did not dig deeper into this issue as we did not anticipate the results. Collect as much data as you can process and handle. If some survey or interview questions turn out to be unnecessary, it is better to have them and not need them than to realize you do not have enough information.

Try to further pinpoint what students enjoy doing. We have just breached the surface of this, and we hope that the next team can use our data and our experiences to improve their IQP's.

# Chapter 5

## Final Conclusions

In the beginning of our IQP journey, our goal was to create a lab that students would simultaneously enjoy and learn from. We had some ideas of what kind of lab that would be, but we really did not have a clear vision those first few weeks of what our IQP would turn into. Through trial and error with Logger Pro, Vernier equipment, and data analysis we quickly learned the right and wrong way to go about being successful.

We learned that students like clear, concise, and sequential instructions that contain pictures to augment the written directions. We were pleasantly surprised that students will be proactive and take charge of their lab experience given the tools. Our extra content panels were an enormous success because of this.

We learned how hard it is to figure out what a student means when they answer a seemingly simple question. We learned that while some students might take a long survey if you stress to them that you need it in order to finish your IQP report, others will still answer their ethnicity as Vulcan. We learned that working with human subjects can be simultaneously infuriating and infinitely rewarding.

Most important of all, we learned the patience and effort it takes to work with friends for three terms in a row. We each grew in our own way over the terms, and often learned the hard way that everyone works differently. We had to learn to trust each other, delegate tasks, keep ourselves focused, and have some fun along the way.

# Appendix A

## Appendix A: The Old Lab

### Instructions

#### A.1 Overview

**Purpose:** The purpose of today's experiment is to verify experimentally that the change of momentum of each object involved in a collision is equal to the impulse acting upon it during the collision, and to show that the overall momentum of the system is conserved during the collision. To do this, you will be conducting an experiment that makes use of two motion sensors (one for each cart involved in the collision) and a force sensor (with which you can determine the impulse acting on each cart).



## A.2 Instructions

**Procedure:** In this experiment, you will be using two carts of unequal mass on the horizontal 2.3-m track, each cart monitored by its own motion sensor located at opposite ends of the track. One of the carts will have a force sensor mounted on it for measuring the impulse involved in the collision between the two carts.

- First adjust the track legs so that the track is as level as possible, as determined by giving a cart first a small push to the right and watching it coast freely, then giving it a small push to the left and watching it coast freely in that direction. When the level of the track has been adjusted so

## A.2 Instructions

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that the coasting seems symmetric in the two directions, then the track is sufficiently close to the horizontal, and you may proceed.

- You will need to make sure that three sensors are connected to the Logger Pro interface: two motion sensors (one at each extreme end of the track) and a force sensor. The force sensor is mounted on one cart such that its force sensing probe will be struck by the other cart during the collision (and please check to see that the force probe sensitivity is set to the 50-N position). The other cart will carry some extra mass so that the masses of the two carts are unequal. The cart with the force sensor should initially be at rest with its cord hanging freely so as not to affect its carts motion after the collision.
- At some point during your experiment, you will need to measure the mass of each of your two carts. When a nearby mass balance becomes available, please take a minute to measure the mass of each cart, each cart outfitted and ready for a collision. In measuring the mass of each cart, be sure to set it on a Styrofoam block on the balance pan so the cart will not roll off the balance pan, but then be sure to subtract off the mass of the Styrofoam block for an accurate mass value for each cart. (Please note that you will have to remove the force sensor cable from the Logger Pro interface when you take the less-massive cart for its mass measurement. Also, you will have to develop a technique for minimizing the effect of the cord on the mass of the cart, recognizing that SOME mass from the cord SHOULD be included.)
- The Logger Pro template will give you a time recording of the force sensor plus the  $v_x$  vs.  $t$  graphs of each cart. Start a recording, give the heavy cart a GENTLE push toward the lighter, stationary force sensor cart, and then read the maximum force recorded by the force sensor during the collision, making sure that it is well within range of the force sensor. During the collision, make sure that the force sensor wire does not impede the motion of the initially stationary cart. Determine the change in velocity and then the change of momentum of each cart during the collision, and compare

each to the area under the force graph during the collision (the impulse!). In principle, the impulse should exactly equal the change of momentum of each cart, so experimentally you should be within a few percent of perfect agreement. AND, the total momentum of the two-cart-system should be same before and after the collision, again to within a few percent.

- **FIRST IMPORTANT NOTE:** Each cart has its own motion sensor to determine its respective  $v_x$  velocity component. The two motion sensors look in opposite directions, however. That means that the motion sensor on the left, records  $v_x$  as being positive from left to right. The motion sensor on the right, on the other hand, records  $v_x$  as being positive from right to left. One way to keep this information organized is to take a moment to create several coordinate systems, one for each position sensor and one for the center of mass system of the carts. Having done the the signs of the velocities for each cart should become clearer, independent of the signs suggested by the Logger Pro graphs. Call on your lab instructor if you are not sure what this first important note is all about.
- **SECOND IMPORTANT NOTE:** The force sensor and the motion sensors sample at a MUCH different rates! Therefore, do NOT expect the impulse duration to line up with the duration of the change-in-velocity profiles. As a result, you should determine CHANGES in velocity from relatively constant  $v_x$  vs.  $t$  plateaus located just before and just after the collision.
- Now of course you will want to determine the change in velocity of each cart from just before the collision to just after (because friction and the force sensor cord are apt to make the velocities change as time goes by). By linking the time axes of each graph before activating the coordinate-determining mode for each graph, you should be able to determine when the collision begins and ends across both graphs simultaneously. Heres how. Under the set of Page commands right above the Toolbar, select the Group Graphs choice that will provide a common time axis for both the force and the two velocity graphs. Then select both graphs. Activate the statistics mode to obtain the mean and standard deviation for the velocities just



before and just after the collision, and the integral mode for a measurement of the impulse. You will be copying your graphs into your lab worksheet, so arrange the pop-up data boxes and the scales of the axes such that they are readable by the grader.

## A.3 Worksheet

**Name:**

**Section:**

**Partner's Name:**

1. Zoom in on your  $F(t)$  data and highlight the area of the curve that you think should be taken to be the impulse of the collision (Integral function). Display this curve, and the one for the velocities, over about a one-second time interval (the same interval for both). Copy and paste the  $F(t)$  plot into this frame, filling its entire width.

2. Write a figure caption for the above, describing the axes and the meaning of the highlighted area. Report the measured value, as determined by Logger Pro.

3. Use the statistics function to get good values for the velocities of the two carts before and after the collision. You should have at least ten datum points for each. Copy and paste the  $v_x(t)$  plot into this frame, filling its entire width.

4. Write a figure caption for the above.

5. From the masses and velocities of the carts, demonstrate whether or not x-momentum was conserved for the system of the two carts. Use a percent uncertainty equal to the largest of the percent standard deviations associated with your velocities. Write a sentence about your conclusion.

6. From the masses and velocities of the carts, demonstrate whether or not impulse equals the change in momentum of the individual carts. Use a percent uncertainty equal to the largest of the percent standard deviations associated with your velocities. Write a sentence about your conclusion.

# Appendix B

## Appendix B: The Code

### B.1 lab.html

```
1 <html xmlns:mso="urn:schemas-microsoft-com:office:office"
   xmlns:msdt="uuid:C2F41010-65B3-11d1-A29F-00AA00C14882">
2 <head>
3   <title>Collisions Lab Instructions</title>
4   <link rel="stylesheet" type="text/css" href="css/
     niftyCorners.css">
5   <link rel="stylesheet" type="text/css" href="css/
     instructions.css">
6   <link rel="stylesheet" href="css/lightbox.css" type="
     text/css" media="screen" />
7   <script type="text/javascript" src="scripts/curvycorners
     .js"></script>
8   <script type="text/javascript" src="scripts/swfobject.js
     "></script>
9   <script type="text/javascript" src="scripts/resize.js
     "></script>
10  <script type="text/javascript" src="scripts/showhide.js
     "></script>
11  <script type="text/javascript" src="scripts/onload.js
     "></script>
12  <script type="text/javascript" src="scripts/prototype.js
```















```

146         <b>Logger Pro</b>: Try reopening Logger
           Pro. Remember to re-zero the force
           sensor.
147         </li>
148     </ul>
149     <br /><br />
150     If the above solutions do not solve the
           issue, there might be a problem with the
           position sensors. Contact your TA for
           assistance.
151     </div>
152 </div><br />
153 </li>
154 </ol>
155 <br />Once you have completed the steps above, you
           may begin the lab.
156 </div><br /><br />
157 <div id="col-one" class="curvyRedraw">
158     <h2>Collision One (Heavy Cart Into Force Sensor)</h2
           >
159     In this collision, you will push a cart with two
           weights into a stationary force sensor. You will
           see an important relationship involving impulse
           and Newton's Third Law.
160 <br /><br />
161 <ol>
162     <li>
163         <div class="steptext">Turn the position sensor
           nearest the force sensor around so its head
           is facing the force sensor. The force sensor
           should be attached to a rod at the end of the
           track.</div>
164     </li><br />
165     <li>
166         <div class="steptext">Close the unused position
           sensor so it is facing upward.</div>
167     </li><br />
168     <li>
169         <div class="steptext">Place the cart with the
           two weights attached on to the track between
           the position sensor and force sensor. <b>The

```



```

191         name='player2 '
192         src='files/player-viral.swf '
193         width='400'
194         height='315'
195         allowscriptaccess='always '
196         allowfullscreen='true '
197         flashvars='file=howtopush.flv.FLV'
198     />
199 </object>
200 <br /><br />
201     We suggest that you push carts in the
        following manner to prevent blocking the
        position sensor:
202 <br /><br />
203     <ol class="reglist">
204         <li>
205             Place two fingers on top of the cart.
206         </li>
207         <li>
208             Push the cart quickly and gently. Note
                that you should remove your fingers
                from the cart and safely out of the
                way of the position sensor's sound
                waves after you have given this push.
209         </li>
210     </ol>
211 </div>
212 </div>
213 </li><br />
214 <li>
215     <div class="steptext">Once the position sensor
        has finished emitting clicking sounds, Logger
        Pro will display one velocity graph with
        data from both position sensors. Only the
        data from one of the position sensors should
        change. Logger Pro will also display a force
        graph for the force sensor.
216 <br /><br />
217     If you are not happy with the way the data came
        out, feel free to conduct the trial again
        before proceeding. Sometimes, it can take a

```













```

330         width="350" />
331     <br /><br />
332     <b>Sections:</b>
333     <ol class="reglist">
334         <li>No movement. Carts are stationary on
            the track.</li>
335         <li>One cart (let 's call it <b>Cart 1</b>)
            is pushed (accelerated) toward the
            other cart (<b>Cart 2</b>).</li>
336         <li>Cart 1 stops being pushed. It travels
            at a fairly constant velocity toward
            Cart 2. The mean of this section is
            Cart 1's initial velocity.</li>
337         <li>The carts collide. Cart 1 decelerates ,
            and cart 2 accelerates.</li>
338         <li>Cart 2 travels down the track at a
            mostly constant velocity. The mean of
            this section is its final velocity.
            Cart 1 also travels at a nearly
            constant (although quite small)
            velocity , which is its final velocity
            .</li>
339     </ol>
340 </div>
341 </li>
342 </ol>
343 </div><br /><br />
344 <div id="col-two" class="curvyRedraw">
345     <h2>Collision Two (Light Into Heavy)</h2>
346     In this collision , you will perform an elastic
            collision between a cart with no weights and a
            cart with two weights attached to it. As you
            perform the collision , observe the relative
            velocity of the heavy cart after the collision to
            the light cart before the collision. You will
            see , first hand, an important relationship that
            is central to conservation of momentum.
347 <ol>
348     <li>
349         <div class="steptext">Reopen the second position

```

```
        sensor and <b>unplug</b> the force sensor.</
    div>
350 </li><br />
351 <li>
352     <div class="steptext">Place the second cart with
        no weights on to the track. Unfold the
        position sensor you removed in the previous
        collison and place it back on the track.
        Swivel around the other position sensor so
        that it is no longer facing the force sensor.
        Slide both position sensors closer to the
        edges of the track , and place the carts
        within the boundaries of the position sensors
        .</div>
353 </li><br />
354 <li>
355     <div class="steptext">You should now have two
        carts on the track: one with no weights , and
        one with two weights. Notice that each cart
        has two small circles of velcro on them. The
        velcro should be facing the opposite
        direction of the collision .
356     <br />
357     <image src="images/lightintoheavy.jpg" width
        ="400" />
358     </div>
359 </li><br />
360 <li>
361     <div class="steptext">Hit <i>Collect</i> in
        Logger Pro , and once you hear the "clicking"
        noises from the
362     position sensors , push the cart with no weights
        into the cart with two weights ,
363     using the same method as the previous collision .
364     <br /><br />
365     Feel free to conduct this collision again if the
        data does not look good.</div>
366 </li><br />
367 <li>
368     <div class="steptext">You should collect the
        following data from the resulting graphs and
```



```

395         &nbsp; Why are the graphs for the two carts
396         inverted?</b></div>
397     <div id="instructions10" class="hidden">
398         Since the position sensors are facing toward
399         each other, they do not agree on a
400         positive direction. In other words, when
401         a cart is traveling away from one
402         position sensor, it is traveling toward
403         another.
404     </div>
405 </div>
406 </li>
407 </ol>
408 </div><br /><br />
409 <div id="col-three" class="curvyRedraw">
410     <h2>Collision Three (Inelastic)</h2>
411     In this collision, you'll conduct an inelastic
         collision between two carts, with no extra
         weights present on either of them. Velcro will be
         used to make the carts stick together upon
         colliding. Since this is an inelastic collision,
         the system will initially consist of two separate
         bodies (carts), and end as one single body (
         stuck together carts). Pay attention to the speed
         of the cart that is pushed, and the speed of
         both carts stuck together after the collision
         occurs. How do they compare? Think about the mass
         of a single cart compared to the mass of two
         stuck together carts. Consider how these concepts
         are related by conservation of momentum.
412 <ol>
413 <li>
414     <div class="steptext">Remove the two weights
         from the cart with weights. You should now
         have two carts with no weights on them on the
         track.</div>
415 </li><br />
416 <li>
417     <div class="steptext">Turn both carts around
         such that the velcro is facing inward.
418 <br />
         <br /></div>
413 </li><br />
414 <li>
415     <div class="steptext">Click on the Collect
         button in Logger Pro, and once the
416     position sensors begin emitting clicking sounds,
         give one of the carts a push
417     toward the other cart, using the same method as
         previously
418     described. Make sure your hand does not
         interfere with the
419     position sensor. The velcro on the carts should
         cause them to stick together
420     upon colliding.
421     <br /><br />
422     If you think your graphs aren't accurate, feel
         free to readjust the setup and run the
         collision again.</div>
423 </li><br />
424 <li>
425     <div class="steptext">You should collect the
         following data from the resulting graphs and
         record it into your data sheet.
426     <br /><br />
427     <u><b>Initial and Final Velocities</b></u>
428     <br /><br />
429     Like in the previous collisions, you need to
         find velocities by taking the mean over
         segments of the velocity graph. Use Logger
         Pro's <i>Stat</i> function for this.
430     <br /><br />
431     <ul>
432     <li>
433         Initial Velocity of the cart you pushed (the
         other cart, which should have been
         stationary initially, has an initial
         velocity of 0 m/s.)
434     </li><li>Final Velocity of the pair of stuck-
         together carts</li>

```



```
459     </div>
460 </div>
461
462
463 </body>
464 </html>
```

This HTML file contains the entire instructions set and references the JavaScript and CSS files which define the style and contain the functions which allow the features of the instructions to work.



## B.2 launcher.html

```
1 <HTML xmlns:mso="urn:schemas-microsoft-com:office:office"
   xmlns:msdt="uuid:C2F41010-65B3-11d1-A29F-00AA00C14882">
2 <HEAD />
3 <script type="text/javascript">
4 window.onload=function(){
5     window.open("lab.html", "one",
6         "left=0, top=0, width=550, " +
7         "height=998, location=no, menubar=no, resizable=yes, "
8         +
9         "scrollbars=yes, status=no, titlebar=no, toolbar=no");
10 window.close();
11 }
12 </script>
13
14
15 <!--[if gte mso 9]><xml>
16 <mso:CustomDocumentProperties>
17 <mso:ContentType msdt:dt="string">Document</mso:
   ContentType>
18 </mso:CustomDocumentProperties>
19 </xml><![endif]-->
20 </head><body />
21 </HTML>
```

This HTML file contains a JavaScript call which launches the instructions in a compact form to easily allow a student to tile the instructions and logger pro next to each other on the screen.

## B.3 instructions.css

```
1 body {
2     font-family: Verdana;
3     color: #000;
4     font-size: 16;
5     background: url("../images/bg.png");
6     background-repeat: repeat;
7 }
8
9 body ol {
10    font-family: Verdana;
11    font-style: normal;
12    font-size: 18;
13 }
14 body ol li {
15    padding: 10px 0px 0px 0px;
16 }
17
18 div.steptext {
19    font-family: Verdana;
20    font-style: normal;
21    font-size: 16;
22 }
23 div.page{
24    width: 1200px;
25 }
26 div.curvyRedraw{
27    background: #FAFAFA;
28    padding: 0px 10px 10px;
29    -moz-border-radius: 20px;
30    -webkit-border-radius: 20px;
31 }
32
33 div.supplementary{
34    position: relative;
35    width: 80%;
36    left: -24px;
37    background: #E0E0E0;
38    color: #000;
```

```
39   border: solid 1px #8B0000;
40   font-size: 16;
41   font-style: normal;
42   font-family: Verdana;
43 }
44
45 .reglist {
46   font-size: 16;
47   font-style: normal;
48   font-family: Verdana;
49 }
50
51 div.hidden{
52   display: none;
53   background: #EDED;
54   padding: 0px 0px 0px 35px;
55   color: #000;
56   border-top: solid 1px #8B0000;
57 }
58 a.showHide{
59   color: #FFF;
60   text-decoration: none;
61 }
```

This CSS file contains the style and format of the instructions set.

## B.4 onload.js

```
1  /**
2   *   Executes functions on page load / resize
3   *   By: Joshua Faucher (jfaucher@wpi.edu)
4   *   Date: 9/27/2009
5   */
6
7
8  /**
9   *   Executes functions after the page has loaded
10  */
11 window.onload=function () {
12     resize ();
13 }
14
15 /**
16  *   Executes functions when the page has changed size
17  */
18 window.onresize=function () {
19     resize ();
20 }
```

This JavaScript file contains the two functions which cause the instructions to dynamically resize when the page first opens as well as each time the size of the browser window changes.

## B.5 resize.js

```
1  /**
2  *  Functions for performing resizes on web elements
3  *
4  *  By: Joshua Faucher (jfaucher@wpi.edu)
5  *  Date: 9/27/2009
6  */
7
8
9  /**
10 *  Resizes the instructions container and supplementary
11 *  divs
12 *  to the size of the document - 20px while the container
13 *  div is less
14 *  than 1000px wide
15 */
16 function resize() {
17     var newWidth = 1000;
18     if (navigator.appName == 'Microsoft_Internet_Explorer')
19         { // If MS Internet Explorer
20             newWidth = document.body.offsetWidth - 80;
21         }
22     else { // Other Browsers
23         newWidth = document.body.offsetWidth - 20;
24     }
25
26     if(newWidth >= 1000)
27         newWidth = 1000;
28     else if(newWidth <= 450)
29         newWidth = 450;
30
31     changeElementWidth("curvyRedraw", newWidth);
32     changeElementWidth("supplementary", newWidth - 20);
33     changeElementWidth("page", newWidth - 5);
34     curvyCorners.redraw();
35 }
36
37 /**
38 *  Reads in an element class in string form and a width in
```

```

    number form
36 * and sets the width of the elements in the class to the
    new width
37 */
38 function changeElementWidth(ElmClass, newWidth)
39 {
40     var elements = getElementsByClassName(ElmClass);
41     for(var i in elements)
42     {
43         document.getElementById(elements[i].id).style.width =
            newWidth;
44     }
45 }
46
47 /**
48 * Reads in an element class in string form and a height
    in number form
49 * and sets the height of the elements in the class to the
    new width
50 */
51 function changeElementHeight(ElmClass, newHeight)
52 {
53     var elements = getElementsByClassName(ElmClass);
54     for(var i in elements)
55     {
56         document.getElementById(elements[i].id).style.height =
            newHeight;
57     }
58 }
59 /**
60 * Reads in a class name in string format and returns an
    array
61 * of the web elements using that class
62 *
63 * Function written by KorRedDevil from Dev Shed Forums
64 */
65 function getElementsByClassName(className)
66 {
67     var hasClassName = new RegExp("(?:^|\\s)" + className +
        "(?:$|\\s)");
68     var allElements = document.getElementsByTagName("*");
```

```
69   var results = [];  
70  
71   var element;  
72   for (var i = 0; (element = allElements[i]) != null; i++)  
73     {  
74       var elementClass = element.className;  
75       if (elementClass && elementClass.indexOf(className) !=  
76         -1 && hasClassName.test(elementClass))  
77         results.push(element);  
78     }  
79   return results;  
80 }  
81 /**  
82  * Resizes the window to a sidebar size  
83  */  
84 function resizeWindow() {  
85   window.resizeTo(500,998);  
86 }
```

This JavaScript file contains the functions which drive the dynamic resizing of the various elements of the instructions. These functions are called by the functions in the *onload.js* file.

## B.6 showhide.js

```
1  /**
2  * Shows / Hides divs based on state
3  * Authors: Joshua Faucher, John Vilk
4  */
5
6  var stateArray = new Array();
7  /**
8  * Reads in a DIV ID and shows or hides it based on the
9  * state stored in stateArray for
10 * that div.
11 */
12 function showhide(layer_ref) {
13     if (!layer_ref in stateArray) {
14         stateArray[layer_ref] = 'none';
15     }
16
17     if (stateArray[layer_ref] == 'block') {
18         stateArray[layer_ref] = 'none';
19     }
20     else {
21         stateArray[layer_ref] = 'block';
22     }
23     if (document.all) { //IS IE 4 or 5 (or 6 beta)
24         eval( "document.all." + layer_ref + ".style.display = " +
25             stateArray[layer_ref] );
26     }
27     if (document.layers) { //IS NETSCAPE 4 or below
28         document.layers[layer_ref].display = stateArray[
29             layer_ref];
30     }
31     if (document.getElementById &&!document.all) {
32         hza = document.getElementById(layer_ref);
33         hza.style.display = stateArray[layer_ref];
34     }
35     curvyCorners.redraw();
36 }
```

This JavaScript file contains the functions which drive the hidden content features



of the instructions.