Lab Revising 101: Revise, Rework, Revamp

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Clarifying the Objectives

William and Mary's Physics 101 is an introductory course for science majors which is made up of three parts: the lecture, the problem session, and the lab. The course description states the purpose of this course as developing "an understanding of the fundamental concepts of physics." Laboratory experience is an integral and necessary part of the introductory physics course and is crucial in providing students with a strong base in physics. Labs for introductory courses have three basic purposes: to teach students the scientific method, to enhance students' scientific literacy, and to aid students' conceptual understanding of the course material.

The first objective, teaching the scientific method, includes teaching students to recognize the importance of documenting their scientific work so that it is repeatable, as well as helping students to analyze the accuracy of data and recognize sources of error. Teaching students the scientific method is the most straightforward objective of the three because it is built into the structure of William and Mary's classic lab assignments. Traditional labs present the student with an objective, procedures, and directions for data collection and analysis. The student will write up a lab report using scientific writing which includes a conclusion where the student explains what the expected outcome of the lab should be and compares it to the actual results. They use error analysis to explain any differences between this theoretical outcome and the experimental outcome. The traditional lab teaches the scientific method because students use the process both while performing the lab and in the lab write-up.

The second objective for the lab is to enhance students' scientific literacy. Scientific literacy refers to the understanding of scientific concepts and possessing scientific abilities that aid students in everyday tasks both within and beyond scientific study.[1] It includes teaching students proper methods of data collection, how to analyze numerical data and other scientific information, and how to understand and effectively use different types of graphs. These are all skills that are necessary for students to effectively participate in discussions of current events, understand economics and finance, as well as analyze any type of scientific information they are presented with. The current labs at William and Mary provide students with opportunities to develop strong skills in scientific literacy through data collection and the analysis portions of the experiments.

The third objective is to improve students' conceptual understanding. To accomplish this goal, experiments should give the students an opportunity to see real-life demonstrations of the concepts they are studying in the lecture and allow them to work hands-on with the type of problems they see in their problem sessions. An effective lab should give physical meaning to the equations the students have been working with. The third objective is the most difficult to meet effectively using the traditional laboratory experiments. William and Mary's current labs are separated into topics which match the concepts being taught in lecture. Unfortunately, certain elements of the labs impede students from making the conceptual connections between what is being taught in lecture and what is being done in the lab.

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[1] *National Science Education Standards*. Washington D.C.: National Academy Press, 1996. National Science Association. < http://www.nap.edu/readingroom/books/nses/html/ >.

The labs concentrate strongly on obtaining the first two objectives, but often do not lend themselves to helping students grasp the concepts behind the experiment. It is necessary to revamp the labs in order to ensure that they meet all of the objectives above. To effectively change the labs the first step is to identify the sources of the problem. There are four main problems with the current labs that keep them from being fully effective. First, some of the labs are generally ineffective at demonstrating the concept that they are supposed to teach because they cannot hold the students' interest and attention. Second, the labs are written using confusing or unclear language. This is a particular problem in the informational sections that are used to introduce the labs. Third, the format and style of many of the labs does not promote active learning. Lastly, writing the lab report is often a task that students gain little from because it is repetitive and they perform it mindlessly. The majority of these problems stem from the fact that traditional labs promote a passive learning style.

The most effective way to increase student understanding is through interactive engagement. Interactive engagement increases conceptual understanding by using techniques such as kinesthetic involvement, increasing student personal responsibility for resolving conceptual conflicts, peer discussion, and Socratic dialogue with instructors.[2] Challenge labs and Socratic Dialogue Inducing (SDI) labs are two methods of applying these techniques which have been shown to be effective. Challenge labs are labs where students are graded on their ability to accurately predict the results of an experiment. They have been shown to improve student concentration on the concepts while they are

[2] Richard R. Hake, "Socratic Pedagogy in the Introductory Physics Laboratory," *The Physics Teacher* Vol. 30, 549 (1992).

in the lab.[3] SDI labs have had similar success. A study shows that students in SDI labs have much higher pretest to posttest gains on Halloun-Hestenes physics concept tests than students in traditional labs.[4] The development of interactive engagement techniques also has positive externalities for the physics department as a whole. The National Task Force of Undergraduate Physics' SPIN-UP Report cited pedagogical reforms as one of the main factors that is needed to create a thriving physics department.[5] These reforms can increase student enrollment, improve students' attitudes, and increase the number of majors in the department.

William and Mary's labs that are based on passive learning need changes to become effective. Some of the labs can be improved simply by changing their style and language in a way that increases engagement, such as adding concept questions throughout the lab, or providing students with better tools to organize data collection and analysis. Labs which have procedures that do not demonstrate the concept they are designed to will be replaced with entirely new ideas that illustrate the concept clearly through interactive engagement.

Improving Effectiveness

The challenge of improving the introductory physics labs is to increase students' conceptual understanding without detracting from the other purposes of the labs. The first step in improving the labs was to determine an effective base style and formatting.

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[3] J.D. Bierman and A.J. Greer, "Challenge Laboratories," *The Physics Teacher* Vol. 43, 529 (Nov. 2005).
[4] Richard R. Hake, "Socratic Pedagogy in the Introductory Physics Laboratory," *The Physics Teacher* Vol. 30, 548 (1992).
[5] *Strategic Programs for Innovations in Undergraduate Physics: Project Report*. Ed. Robert C. Hilborn, Ruth H. Howes, and Kenneth S. Krane. Febuary 2003. American Association of Physics Teachers

The style needs to encourage students to think about the physics concepts involved in the lab and how they connect with the experiment they are performing. The formatting and language of the experiment should be as clear, concise, and organized as possible so that students can focus their attention on developing their understanding of broad concepts instead of spending time and patience trying to understand how to perform the lab. We began creating a strong base format by changing the style and placement of the informational sections, adding conceptual questions, and organizing data sections.

To test the effectiveness of the change in style and to refine the labs' design we created a sample lab to test on students. We began with the original conservation of momentum lab, which is lab 7 from the student lab book, and applied the new style without changing the actual lab experiment. We chose the conservation of momentum lab for three reasons. While the experiment itself is capable of providing students with a physical understanding of the concept of momentum, the format of the lab prevents student comprehension because of its tedious nature and confusing language. Lab 7 is also a good candidate for testing the effectiveness of a new style because the original experimental procedures are already effective at engaging students and creates a sound physical picture of the concept of linear momentum. Choosing a good lab as the control reduces bias during the comparison of the old and new labs. Limiting the changes that are made to the original lab has the same effect as limiting the number of independent variables in an experiment. It makes it easier to pinpoint the sources of negative and positive feed-back. This ensures that any increase in effectiveness can be attributed to specific stylistic changes to the lab, and not just to revision of the lab as a whole.

A new version of lab 7 was created by applying the principles of effective labs from the research we preformed. The new version of lab 7 can be found in Appendix A.[6] The main problem of the original lab is a lack of clarity in the writing, and a style and presentation of concepts which is poorly organized and does not lead students to think for themselves. These issues were addressed first by adding conceptual questions throughout the lab. Questions were interspersed throughout the information sections replacing tedious explanations of the material so that students were guided to think about the concepts rather than being spoon-fed information. Concept questions were also placed throughout the analysis section to help students connect experimental data to the ideas in the information section. Similarly, the information sections were spread throughout the lab. This has a dual purpose. First, it further connected the general concepts to the experimental data. Second, it broke the information into smaller more manageable chunks that students are more likely to read and internalize. The next measure performed to change the lab was that the language and syntax throughout the lab were edited to enhance its overall clarity. Lastly, to cut down on confusion, organized data and analysis sections were added to the lab. These new sections provide blanks for students to write down data as they collect it. Organizing data teaches students good habits in data collection and provides a check to make sure that students are on track, as well as speeding up the pace of the lab thus making it less tedious.

In the week before the students preformed the original lab for class we held three trial sections of the new experimental lab. After performing the experimental lab, students filled out a survey which included both quantitative and qualitative sections.[7]

[6] See Appendix A-1 for a copy of lab 7
[7] See Appendix B for a copy of the surveys used

The quantitative section posed questions which students answered using a scale from 1-5, where 1 was the best and 5 was the worst. The qualitative section asked the students open-ended questions about which parts of the lab they liked and disliked, as well as asking for suggestions on how the lab could be improved.

After each trial, the survey results were used to make improvements to the experimental lab for the next trial. After trial 1, the analysis directions were moved so that they directly followed the experimental procedures and a reference to formula numbers was added to the analysis directions. The conceptual questions were numbered and bolded to give them emphasis. Finally, the sections of the lab were given new numerical labeling to aid clarity. After trial 2, the equation definition of momentum, $p=mv$, was added to the introductory information. No additional changes were made to the lab after trial 3.

The surveys from the traditional lab were used as a control to compare with the results of the trials' surveys. When the students completed the traditional lab in class the next week they filled out a survey in reference to the original version of the lab. The group of students which filled out a survey about the original lab included both students who took the new lab in the week before as well as students who had only performed the traditional lab. This provided a wider array of perspectives for comparison. The survey was the same survey used in the experimental trials, but had an additional question asking how much time students spent on the traditional lab because the length of the new lab was one of the most common student concerns. The question asked students how much time they spent on the traditional lab which was compared to the time they spent on the new lab. It also provided information on how students view effectiveness of traditional labs and lab reports.

Results

The quantitative survey information was compiled in graphs showing responses to each of the five questions.[8] This was done for the control group, for each trial separately, and for the combined responses from trials 1, 2, and 3. The qualitative information was organized by trial to show what comments were made and how often. A selection of the quantitative findings can be found in Appendix C-1, and the qualitative findings can be found in Appendix C-2.

The quantitative results show marked improvement in student responses for the new lab on four of the five questions. For the trials, the responses to questions 1, 3, 4, and 5 are generally "very good" or "somewhat good" creating a curve that is heavy on the left hand side. For the control, the responses to the same questions are generally centered around "neutral," creating a bell shaped curve. This means the students in general prefer the layout of the new lab. Quantitative results show that students believe that the order information was presented in was beneficial to their understanding of the concepts in the lab, and that the informational sections were clear. They also found that the organization of the data and analysis sections added to their understanding of the material.

The question where there was little difference between the response to the new lab and the old lab was Question 2. It asks: How clear were the procedures? The answers for both the trial and the control groups are centered around "somewhat good."

[8] A copy of the quantitative results can be found in Appendix C-1. The qualitative data can be found in Appendix C-2

This is consistent with the changes that were made to create the new lab because the basic procedures were changed very little, meaning there should be little change in students' opinions of the procedures.

The qualitative analysis provides similar results. During the trials, changes in the lab from one trial to the next are apparent as students no longer cite issues that have been dealt with as problems. Also, the number of different complaints decreases and students focus on the length and procedure of the lab. The positive feedback also increases from trial to trial with the number of positive comments outweighing the number of negative comments in trial 3. In the control survey, the number of negative comments heavily outweighs the number of positive comments. The most common comment in the trials, that the lab was too long, is also the most common comment in the control group. To determine if the new lab is more efficient than the traditional lab we compared the length of time students spent on each lab. On average students completed the new lab in an hour and a half which is the same amount of time it took students to complete the traditional lab.

Additionally, in the original lab students also had to complete a lab report which took an average of two hours and fifty minutes to complete. Sixty-six percent of students said that the traditional lab and lab report were not an effective use of their time. This shows that although students said that the new lab was too long, it was still an improvement over the original lab. Since one of the main goals of this project is to enhance the lab experience it is important to understand how the traditional lab report aid's student understanding. While lab reports are an important part of learning and understanding the scientific method, their benefits must be weighed against their costs.

Lab reports are often tedious and time consuming especially if the lab procedure itself is long or if the lab includes many parts. In these cases students may often benefit more from writing a shortened version of the lab report which only includes the purpose, data analysis and conclusions. Also, students are generally able to write a good lab report after their third try, so continuing to work on a skill that they have mastered frustrates students. If students only have to prepare a full lab report for a few labs they will concentrate more on doing those reports well. Not only that, but the less daunting, short reports will allow students more time to think about the concepts rather than the layout and style of the report.

Putting Theory into Practice

The results of the tests on lab 7 show the overall effectiveness of the new lab style. These techniques can be applied to and expanded upon throughout the lab manual. There are three labs in particular which caught our attention and received changes based on the results of lab 7. [9] We also added a new introduction to the lab manual which better reflects the tone of the new labs. Additionally, we provided two reference sections. [10] The first one gives a sample example of how to format a lab report which details the information that should be present in each section. We also included tips on writing a successful lab report. The second reference section gives information on using excel so that students can more easily organize and analyze the data they collect in lab.

[9] The new labs can be found in Appendix A-1 – A-4
[10] The reference sections can be found in Appendix A

Lab 4: Vectors and Forces

This lab was similar to lab 7 in that the original experimental procedures provide a good physical picture of the concept the lab is trying to demonstrate, but its poor structure along with its excessive use of technical equipment impede interactive engagement. The original lab made heavy use of force tables to demonstrate the relationship between forces. When used correctly, the force table is a wonderful tool for demonstrating the role that vectors play in balancing forces, but it provides no connection between the physics in the experiment and the physics that students experience in everyday life. Also the force table allows students to guess and check to find the correct balance instead of using physics and vector addition. Additionally, half of the original lab 4 is devoted to explaining the concept of vectors as well as teaching students how to use them mathematically. This section of the lab seems more like a math lesson than a physics experiment. The lab is supposed to be part of class where students are expected to have a calculus background, so re-teaching the students vectors is redundant. The vector portion of the original lab does not provide a physical meaning to the mathematical concept of a vector and takes up valuable lab time which should be used to engage the students.

In revamping lab 4 we applied the same basic stylistic changes which were used on lab 7 such as clarifying the language, adding concept questions throughout the lab, organizing the data and analysis sections, and changing the order in which information was presented. We also made changes to the experiment itself.[11] In order to make the lab less passive and remove the guess and check process from the force table portion of the lab we decided to use the idea of a challenge lab. At the end of the new lab students

[11] The new version of lab 4 can be found in Appendix A-2

will be graded on their accuracy in balancing a force table on the first try. This has two benefits. Students are much more likely to use the proper method for calculating the balance in the rest of the experiment when they know they will be tested on it. Then by using the proper method, students are forced to really think about the concept they are using instead of just rushing through the experiment without ever understanding it.

The other major change made to the lab was removing the section which teaches vector math and replacing it with a hands-on project which gives students practice using vector math. For this project students are given two points around the building which are difficult to measure between, such as a point in a room upstairs and a second point in a room downstairs. Students will be divided into teams and given string, a protractor and a yardstick as the only tools they are allowed to use to measure the distance between the two points. In measuring this way students will see that each piece of string can be represented by a vector because it will have a length and a direction. It is a tool to help students visualize the concept of a vector in every day life. In addition to measuring the distance using vector addition, the students are asked to make sure that their method is repeatable. This means that students will have to document their procedures which reinforces the concept of scientific method.

Lab 8: Conservation of Energy (Disk and Block on Track)

The original version of lab 8 was another lab where its structure and style inhibit students from seeing the connection between the experiment and the concept in the world around them. There are two main problems in the original lab which need to be addressed in order to improve the lab. The first and most urgent problem is the method of data collection in the original lab. Students are instructed to use a motion sensor at the end of the track to measure the position of the rolling disk. They then use the position data to find the acceleration of the disk. They compare this to the theoretical acceleration which they find using the equation:

$$a = \frac{g\sin\theta}{1 + \frac{I}{Mr^2}} \qquad (1)$$

The objective of the lab is to teach students about the relationship between rotational motion and energy. Generally, energy is calculated as a function of velocity, not acceleration. The arbitrary choice of having students calculate acceleration instead of velocity clouds the true objective of the lab. It requires students to use a string of equations to solve from displacement to velocity to finally find the acceleration. This process is confusing to students and does not make sense given that the focus of the lab is energy. It is also difficult for students to connect the measurement of acceleration back to the concept of energy because there no clear relationship between the two, and so the comparison loses much of its physical meaning. The second problem of the original lab is that it introduces the concept of combined rotational and translational energy without providing students with an example of purely translational energy. An experimental example of purely translational energy acts as a standard of comparison for the effects of rotation on the energy of a system.

To solve these problems we created a new version of the lab.[12] First we wrote a different procedure for collecting and analyzing the experimental data. The new directions have the students collect the position and velocity directly using motion

[12] The new version of lab 8 can be found in Appendix A-3

sensors. The information is passed into Data Studio where the students can manipulate it and use it to find the energy. The students then compare the experimental velocity to the theoretical velocity using the equation:

$$v = \sqrt{\frac{4g\left(h_o - h\right)}{2 + \left(\frac{R}{r}\right)^2}} \tag{2}$$

This provides students with a straightforward way to see the relationship between rotational motion and energy.

We also changed the lab by adding a new section which focuses on the energy of translational motion. Students perform this part of the experiment at the beginning of the lab. They use a motion sensor to record the velocity and position of a block sliding down the track. Then they find the kinetic energy of the block. The energy of translational motion of the block is later compared to the combined translational and rotational energy of the rolling disk. The comparison emphasizes how rotation affects the disk's velocity as well as its total energy. These changes greatly enhance student engagement in the material. Additionally the style and language were changed to enhance the clarity of the lab and concept questions were added throughout.

In order to determine the effectiveness of new version of lab 8 we had students perform the lab and complete a survey about their experience. The survey used was the same one which was used during the trials for lab 7.[13] The trial group was made up of 14 students taking introductory physics. The quantitative results were very positive.[14] The responses were almost exclusively "very good", "good", or "neutral." The average response for each question was a 2, which is "good." The qualitative comments were

[13] The survey can be found in Appendix B
[14] The quantitative results can be found in Appendix D-1

also very positive.[15] Specifically, students liked the ease of data collection and use of Data Studio to aid analysis. They also appreciated the organization and clarity of the lab. The most frequent problem students cited from the lab was that no uniform block was provided for the translational portion of the lab.

Lab 3: Motion with Constant Acceleration

The original lab 3 uses the air table to demonstrate motion with constant acceleration in one and two dimensions. It has students practice applying the kinematics equations using the position graphs that the air table creates. One of the expressed goals in revamping the physics 101 labs was to reduce the use of the air table which is used excessively in the labs. Analyzing the data from the air table is difficult and tedious. Also, although the motion of the puck on the air table is a useful example of motion with constant acceleration, it does not show students how universal motion with constant acceleration is. Motion with constant acceleration is a constant occurrence in everyday life, and the equipment of the air table distracts students from realizing the importance of physics in the world around them.

Because there are so many more powerful examples of motion with constant acceleration we decided to entirely replace the original lab with an idea which brings a fresh perspective to the concept. We took the simple idea of a ball being tossed in the air, which is often used in practice problems, and created an experiment based on it. We wanted to capture the path of a ball through the air so that students could see how it actually moves. To take a photo which shows the ball at different points along its path we combined a long exposure digital photo with a strobe light. The experiment has

[15] The qualitative comments can be found in Appendix D-2

students toss a ball to one another while a strobe light flashes. The periodic bursts of light illuminate the ball as it travels through the air. The result is an image where the ball appears every time during the exposure that the strobe flashed. When students see the image they will see that the ball really does move in a parabola. They will realize that the kinematics equations are more than an approximation, and can truly describe motion with constant acceleration.

Not only will the image show students physics working in everyday life, it will also be used to give the students practice manipulating the kinematics equations. They will use the kinematics equations to figure out the initial angle and speed of the throw. To keep the analysis from becoming tedious and help the students use the equations we wanted to create a computer program to be used in conjunction with the lab. We created a detailed set of requirements[16] for a program called the Kinematics Manipulator, but unfortunately we did not have time to write the code for the program. We did create a sample run-through of the program to show how the program would work if completed, it can be found in Appendix E-2.[17] The students will take the photo and download it into the Kinematics Manipulator. It will help them find the equation of the ball's path by creating a regression of the points where the ball appears. Then students can find the maximum point of the ball's path where the velocity in the y direction equals zero. With this information students can find the initial velocity of the ball and the angle at which it was thrown.

The Kinematics Manipulator also aids students in applying the information to the kinematics equations. The program allows students to click on the equations in the

[16] The requirements can be found in Appendix E-1
[17] The demonstration of the computer program can be found in Appendix E-2

program and rearrange them in various ways. This helps students to figure out the best way to solve for the quantities they want without the frustration of scratching out different forms of the equations with pencil and paper. The ability to see the different forms of the equations also demonstrates their versatility and utility to the students. Once students figure out what form of the equations they want to use they can input the data they know into the program. Then the program will apply the information to the equations they have chosen giving them a value for the variable they want.

Conclusions

The set of labs that we created are a solid base which we hope the department can use to strengthen its introductory lab program. All four new labs have a style which enhances interactive engagement. They help students to discover the concepts for themselves, and the labs now include activities that students can enjoy. We truly believe that using the improved labs would be beneficial to both introductory students and the department as a whole. We hope that the research we have done serves to help others who might wish to make improvements to the remaining labs.

Appendix A – The New Labs

Introduction to Physics 101 Labs

The Study of physics looks for an explanation to everything in the world—why planets circle the sun, why everything falls with the same acceleration on earth, why negative charges attract positive ones. Like many other phenomenon, there is a simple explanation why you are all enrolled in Physics 101L: because the department forces you. It is impossible to understand physics, even at the most basic level, without any sort of hands-on experimentation. Because what you are to learn this semester is so fundamental to the study of physics—and, indeed, the study of science itself—it is pertinent that you fully comprehend the presented material. In order to ensure this complete and total comprehension, one must perform labs as well as attend class.

This year, in both lab and lecture, you will learn a number of important physical concepts and theories, information that men and women have devoted their lives to determining. We cannot promise that you will remember every detail of every lecture, or that you will be able to recall a single lab you performed five years from now. What we hope you take out of this class and lecture, rather, is a better understanding of the scientific process and scientific thinking. For those of you interested in a career in science, this will undoubtedly prove a vital, necessary, and fundamental tool. For those of you who will not embark on such a career path (including, truth be told, one of the editors of this manual), there is still much to learn in this lab. You cannot read a newspaper today without seeing some reference to science or technology. Nor can you perform a logic puzzle without utilizing the basic analytical tools you will develop and refine in the labs to come. In order to function as an educated member of today's society, you must develop, grasp, and show a keen sense of analysis, logical processing, and scientific thought. These Physics 101 Labs, then, are not merely an introduction to physics but also an introductory class in how to be a responsible human being.

Name
Lab Partner: Their Name
Lab Section
Date

Lab #: Title

Purpose: In this section, you discuss the motivation of this lab and detail any relevant background information to the lab, such as laws, equations, or unit analysis. The main idea is to discuss why this lab is important and necessary in furthering your education of physics. A typical purpose statement is a short paragraph.

Procedure: In a clear, organized manner you will briefly summarize the steps of the lab. This section should *not* be a word-for-word copying from the lab manual itself. It is your responsibility here to note what you did, how you did it, and what equipment was utilized. The language should be clear and concise, so that someone outside of the lab could understand what you did and replicate it if needed.

Data and Analysis: In this section you record all raw data you collected using graphs, data tables, and any equations provided either in the lab itself or in lecture. It is pertinent that you show your calculations in this section so that others may know exactly how you obtained your conclusions. Do *not* exclude any data, even if you feel that it is a source of error. Include it, demonstrate the error (if possible), and explain why the error exists. It could be a malfunction of the equipment, for instance, or simple human error in making precise calculations. Furthermore, discuss any uncertainties, surprises, problems, or concerns that arose during the lab itself, and how these could be avoided or resolved in the future.

It is imperative that this section is technically sound. Therefore, include all calculations and use the correct units. If necessary, perform dimensional analysis to demonstrate how your units were determined. Furthermore, label every graph, figure, and equation with an identifying number, and be certain to title your graphs and label your axes. Any time a figure is introduced, be it a graph, data table, or illustration, be sure to follow it up with an explanation of its importance to the lab and/or the analysis of it, as well as any conclusions that may be drawn from it.

Conclusions and Error Analysis: At the end of the lab, you have the opportunity to discuss whether or not the lab confirmed both the law being tested and your hypothesis of it. Furthermore, you also must perform error analysis to demonstrate how closely your performance of the lab was consistent with what the theory predicted. For more on error analysis, please see Lab 1.

Experimental science is different from many other disciplines in that there need not always be a "correct" answer. Nor must one discover said right answer to learn from the experiment. If you do not achieve the correct answer, do not give up and deem your lab a failure. Instead, look to reasons and explanations for why you did not achieve what you had hoped to. Was the equipment faulty? Were incorrect, or incorrectly performed, equations utilized? Was the procedure followed exactly, or were mistakes made in the execution of the lab itself? Is the theory, in fact, correct? So long as you search out an explanation for the reasons why your lab was not perfect, it was not a failure performed in vain.

Notes about the Lab Report

- Write clearly, so that even one who did not perform the lab may understand the steps and results.
- Provide only the relevant information—not too much that it becomes superfluous, but not too little that it leaves the reader befuddled..
- Number your pages.
- When possible, type your labs. Microsoft Word and WordPerfect are excellent computer programs, and the Equation Editor in Word makes formatting equations quite simple. Furthermore, Microsoft Excel is an excellent tool to use for making graphs.
- Use correct grammar and syntax.
- Spell correctly. Do not rely on spell-check for accuracy.
- Clearly mark and distinguish each section.

Microsoft Excel How-To

Microsoft Excel is a powerful tool, especially in the physics lab. It allows for the collection and organization of data, as well as the construction and production of graphs. As with many tools, however, the software is only useful if you understand to use it. The following instructions on creating graphs in Microsoft Excel should not be considered to be extensive or all-encompassing. Rather, they are intended to provide a skeletal framework from which you can develop your own experience and familiarity with the program.

- Type or input your data into the columns provided in one of the worksheets in Excel. Make sure you keep the different variables in separate columns so as not to negatively affect your results.
  - Hint: Once you get more skilled using Excel, you may also use it to help with your calculations rather than doing them by hand or calculator.
- Highlight the columns of data that you would like to graph, and then click on the Chart Wizard icon on the toolbar. The Chart Wizard icon has a red, blue, and yellow graph of columns displayed on it.
- Select the type of graph you would like under the Column Types tab. For line graphs, select the "X-Y Scatter" option. To determine if your data results make physical sense, you may select the "Press and Hold to View Sample" button to view the graph of the data.
  - Note: This graph may appear tilted or cockeyed if what you have wanted to be the x- and y-values have been reversed by the software.
- Hit "Next," and you will be sent to the Source Data window. To change which values are on which axis, press the button with the red arrow to the right of the "X Values" or "Y Values" box. To select the data for that particular axis, highlight it with the box with the flashing dotted line. The "Next" button will bring you to the Chart Options window.
  - Note: If at any time you want to undo an action in a previous window, select the "Back" button.
- In the Chart Options window, under the Titles tab, you may label the axes and the graph itself. Make sure to include any relevant units in the labels. Under the Gridlines tab, you may show or delete the gridlines as you desire. Lastly, the Legend tab will allow you to hide the graph's legend if you so desire.
- Click "Next," and you will be sent to your last window, which will allow you to determine where you would prefer to place the new graph. You can choose to store it on the sheet in which your data is stored, or you may create an entirely new sheet solely for the graph. That is entirely up to your discretion. Then click "Finish."
- To change the color of the plot area, double click any part in the background of the graph and select which color you would prefer.
- To create a line of best fit, right-click on one of the data points. An Add Trendline window will appear, and you can decide which kind of line you would like the line of best fit to be. Clicking the Options tab, you can choose to display the equation for this line on the graph. This is at your discretion, but it may prove helpful in later calculations, especially if you will need to differentiate or integrate at any time during these calculations.

Appendix A-1

7 Conservation of Linear Momentum

7.1 Purpose – to demonstrate the principles of conservation of linear momentum

7.2 Equipment

- Air table
- Magnetic pucks
- Rubber band
- Scissors
- Velcro collar
- Lead collar
- Protractor and plastic ruler
- Two yard sticks

7.3 Special Caution

- Do not touch the air table or pucks while the spark timer is on.

7.4 Conservation of Linear Momentum

The total linear momentum, $p = mv$, in an isolated system always remains constant. An isolated system is a system that doesn't interact with the rest of the world. This means that the sum of all the forces on the system arising from the rest of the world is zero. If the system is an isolated group of particles, the total linear momentum of the particles after collisions equals the total linear momentum from before the collision.

The law of conservation of momentum is useful for determining the motion in the system especially when we do not understand how the internal forces within the system interact. For example, we can determine the paths, velocities and masses of atoms in a collision even though we do not completely understand the specific nature of inter-atomic forces.

Kinetic energy, unlike linear momentum, may not be conserved even in an isolated system. Particles' initial kinetic energy may be expended in heating during the collisions.

Since momentum varies **linearly** with velocity, momentum conservation yields equations in linear velocity. Kinetic energy on the other hand varies with the **square** of velocity, so it is characterized by quadratic equations.

This lab examines several experiments in conservation of momentum by using moving pucks. The sum of all the external forces acting on the puck system is zero and friction is minimized by using an air table to support the pucks.

7.5 General Experimental Procedure

In parts 7.6, 7.7, and 7.8 we will use an air table with sets of magnetic and non magnetic pucks and Velcro collar strips to better understand the concept of conservation of momentum through three experiments. In the first experiment, magnetic pucks will be used to simulate an explosion. In the second experiment, the Velcro collar strips will be used to simulate perfectly inelastic collisions. In the third experiment, the magnetic pucks will be used to simulate perfectly elastic collisions. A lead collar placed on one of the two pucks will simulate unequal mass explosions and collisions. Before beginning any of the specific experiments follow these steps:

- Weigh on the lab scales provided 1) the magnetic pucks 2) the non-magnetic pucks with the Velcro collars attached 3) the lead collar.
- Turn on the air supply and level the air tables by adjusting its legs until the pucks remain approximately at rest when released.

General procedure information for the use of the air table in parts 7.6, 7.7, and 7.8:

- Always set the spark timer frequency, $f_{spar\,\mathrm{ker}} = 20Hz.$.
- Always turn the spark timer off just before a puck hits the edge of the air table. This avoids overlaying the initial puck trajectory spark dots with those made after the puck hits the table edge. Don't forget to label each track with its associated puck

7.6 Explosions

7.6.1 Background Information

Consider an explosion where a body at rest explodes into two pieces. In an isolated system conservation of linear momentum gives:

$$m\vec{v}_i = m_1\vec{v}_{1f} = m_2\vec{v}_{2f} = 0 \qquad (1)$$

where m and v_i are the mass and velocity of the original object, and m_1, v_{1f}, m_2, and v_{2f} are the masses and velocities of the two pieces after the explosion. (see Figure 1). Solving for v_{1f} gives:

$$\vec{v}_{1f^y} = -\frac{m_2}{m_1}\vec{v}_{2f} \qquad (2)$$

The minus sign indicates that the pieces are moving in opposite directions.

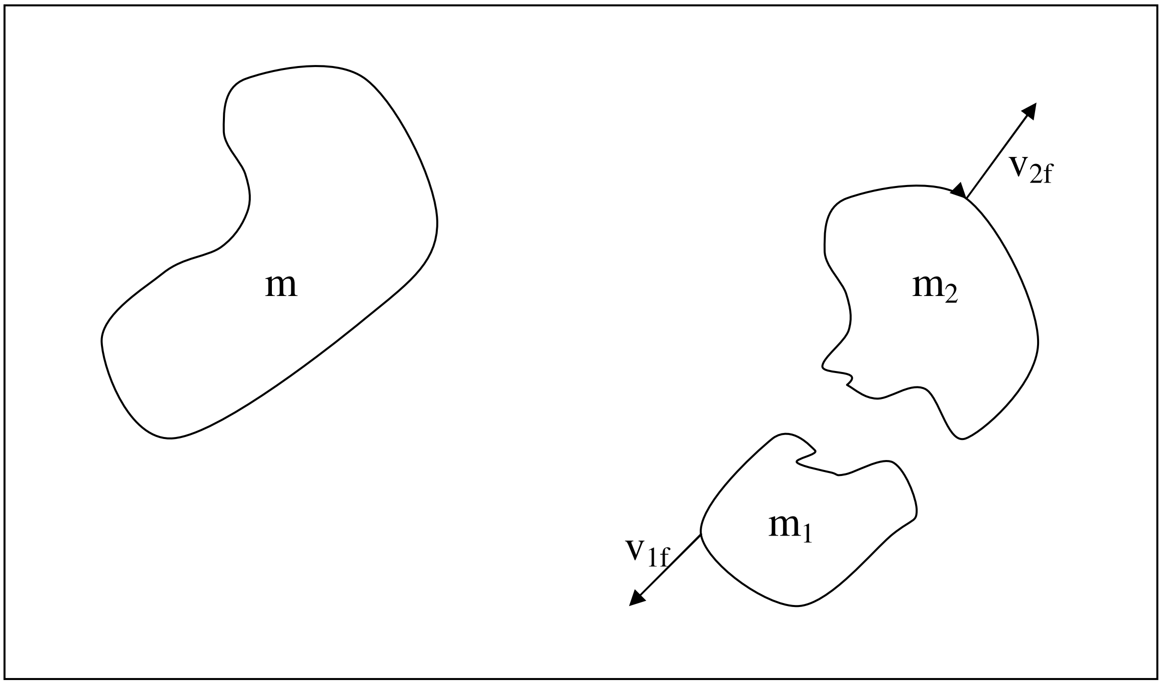


Figure 1

Before the explosion the total kinetic energy of the system is zero; however, after the explosion the system kinetic energy is not zero.

Q1) Why does the kinetic energy change?

Q2) Is total energy conserved? Why or why not?

7.6.2 Procedure for Explosion Simulation

- Place a sheet of white paper on to of a graphite sheet on top of the air table.
- Place two magnetic pucks, with the lead collar on one puck, on the white sheet next to each other.
- Place the rubber band around the rims of the two pucks so that they are held together.
- Make sure that the pucks are at rest, then start the sparker and cut the rubber band

- When the rubber band breaks, the pucks will be repelled from each other. Stop the timer before either puck hits the table edge.
- Label the resulting trajectories and remove the white sheet for analysis.

7.6.3 Analysis of the Puck's Trajectory

- For each trajectory leg, (e.g. trajectory of puck #2 after collision), measure the inter spark dot spacings, Δx .
- Find their average $\overline{\Delta x}$.
- Calculate the puck's velocity on the trajectory leg, $v = \frac{\overline{\Delta x}}{\Delta t}$, where $\Delta t = \frac{1}{f_{sparker}} = \frac{1}{20}\text{sec}$.
-
- Using your measured values of the puck masses, calculate the magnitude of the puck's momentum, │p│ =mv, and the puck's kinetic energy, KE=1/2 mv2 for each leg.
- Using a protractor measure and record the angles of the trajectory legs, θ with respect to the x-axis.
- Calculate the *x* and *y* components of the puck's momentum, p_x and p_y. For example, the *y* component of the outgoing momentum of puck #2 equals $m_2\bar{v}_{2f_y} = m_2\bar{v}_{2f}\sin\theta_{2f}$.

7.6.4 Data Collection and Analysis

Note: For ease draw the x-axis along the direction of one of the two outgoing pucks. Use equations (1) and (2) from the background information to aid in your analysis

Puck #1 $\overline{\Delta x}$ = ______

v = ______

│p│ = ______

KE = ______

p_x = ______ p_y = ______

Puck #2 $\overline{\Delta x}$ = ______

v = ______

│p│ = ______

KE = ______

p_x = ______ p_y = ______

Q3) How well are the before/after *x* and *y* momentum components conserved?

Q4) Explain your results, is this what you expected? Why? Make sure to explain any discrepancies between your data and your expectation.

Collisions

General Background Information

A collision occurs when projectile collides with a target that is initially at rest. Conservation of momentum in an isolated system gives:

$$m\vec{v}_{1i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f} = 0 \qquad (3)$$

There are two unknown vectors on the right hand side, v_{1f} and v_{2f}. Even if v_{1i} is given, we cannot uniquely determine v_{1f} or v_{2f}. To solve for the two unknowns we need to use some subsidiary condition such as the elasticity, which is the amount of kinetic energy that is conserved, to give us a second equation. A perfectly elastic collision exactly conserves kinetic energy. A perfectly inelastic collision the colliding bodies stick together and kinetic energy is not conserved.

7.7 Perfectly Inelastic Collisions

7.7.1 Background Information

Let us assume that the collision is perfectly inelastic; the two bodies stick together after the collision so, $\vec{v}_{1f_y} = \vec{v}_{2f} = \vec{v}_f$. By conservation of momentum, v_f is along the same path as v_{1i}. This gives:

$$m_1\vec{v}_{1i} = (m_1 + m_2)\vec{v}_f \qquad (4)$$

and by rearranging equation (4) we get:

$$\vec{v}_f = \frac{m_1\vec{v}_{1i}}{(m_1 + m_2)} \qquad (5)$$

Let us calculate the fractional kinetic energy loss, $\frac{\Delta KE}{KE}$, which is called the inelasticity:

$$\frac{\Delta KE}{KE} = \frac{KE_i - KE_f}{KE_i} = \frac{\frac{1}{2}(m_1\vec{v}_{1i}^{\,2} - (m_1 + m_2)\vec{v}_f^{\,2})}{\frac{1}{2}m_1\vec{v}_{1i}^{\,2}} \qquad (6)$$

By substituting equation (5) we have:

$$\frac{\Delta KE}{KE} = \frac{\frac{1}{2}\vec{v}_i^{\,2}\left(m_1 - \frac{m_1^2}{m_1 + m_2}\right)}{\frac{1}{2}m_1\vec{v}_i^{\,2}} = \left(1 - \frac{m_1}{m_1 + m_2}\right) \qquad (7)$$

Q5) If the projectile and target have the same mass, what will the inelasticity be from their collision?

7.7.2 Procedure for Inelastic Collision Simulation

Equal Masses

- Place a sheet of white paper on top of a graphite sheet.
- Place two non-magnetic pucks, with Velcro collars attached, on the white sheet.
- Place one puck at the center of the table as the target.
- Place a yard stick on either side of the two pucks to create a straight runway for the pucks to travel in. This ensures that the collision is a precise head-on collision.

- With an insulating stick, (to avoid shock), push the projectile puck toward the target puck in a precise head-on collision.
- Remove the yard sticks before the collision occurs. If it is a precise head-on collision the pucks should not rotate around one another. You may need practice a few times with the sparker off to get a correct collision.
- Remove the white sheet for analysis.

Unequal Masses

- Place a fresh sheet of white paper on the air table. Use as a target a puck with a lead collar on it.
- Repeat the collision procedure above. Remember to label trajectories.

7.7.3 Analysis of the Puck's Trajectory

- Follow the procedure in part 7.6.3

7.7.4 Data Collection and Analysis:

Note: for ease draw an x-axis along the initial direction the projectile puck. Use equations (3) through (5) to aid your analysis.

Equal Masses

Before: $\overline{\Delta}x$ = ______	After: $\overline{\Delta}x$ = ______
v = ______	v = ______
$\lvert p \rvert$ = ______	$\lvert p \rvert$ = ______
KE = ______	KE = ______
p_x = ______ p_y = ______	p_x = ______ p_y = ______

Q6) How well are the before/after *x* and *y* momentum components conserved?

Unequal Masses

Before: $\overline{\Delta x}$ = ______

v = ______

$|p|$ = ______

KE = ______

p_x = ______ p_y = ______

After: $\overline{\Delta x}$ = ______

v = ______

$|p|$ = ______

KE = ______

p_x = ______ p_y = ______

Q7) How well are the before/after *x* and *y* momentum components conserved?

Q8) Calculate the inelasticity for the unequal collision.

Q9) How does the unequal mass affect the momentum and kinetic energy of the pucks?

Q10) Explain your results, is this what you expected? Why? Make sure to explain any discrepancies between your data and your expectation.

7.8. Perfectly Elastic Collisions

7.8.1 Background Information

Let us assume that the collision is perfectly elastic. This means that after the collision the projectile and target do not stick together and that they emerge from the collision having the same total kinetic energy as the initial projectile had.

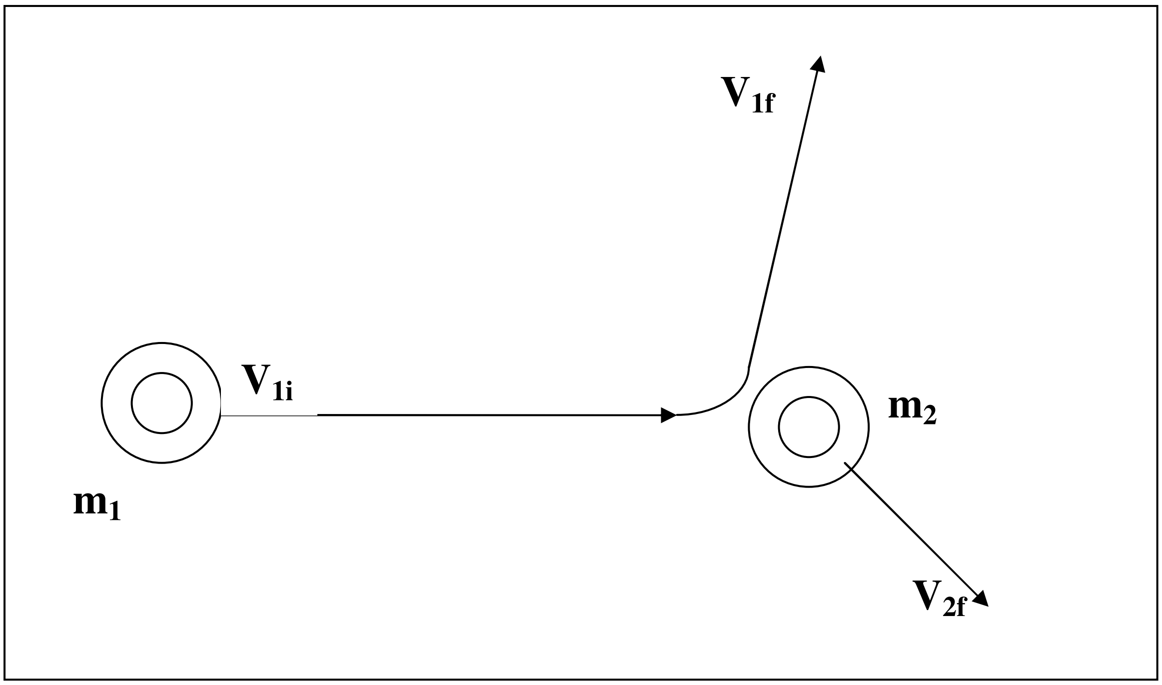


Figure 2

In this case v_{1f} is not necessarily equal to v_{2f} . However, by conservation of the *x* and *y* components of momentum (where the *x* and *y* directions are *parallel* and *perpendicular* to v_{1i}):

$$m_1 v_{1f_x} + m_2 v_{2f_x} = m_1 v_{1i_x} \qquad (8)$$

$$m_1 v_{1f_y} = -m_2 v_{2f_y} \qquad (9)$$

There is also a third equation for the conserved kinetic energy for a perfectly elastic collision:

$$\frac{1}{2} m_1 \left(v_{1f_x}^2 + v_{1f_y}^2 \right) + \frac{1}{2} m_2 \left(v_{2f_x}^2 + v_{2f_y}^2 \right) = \frac{1}{2} m_1 \left(v_{1i_x}^2 + v_{1i_y}^2 \right) \qquad (10)$$

With a v_{1i} given, equations (8), (9), and (10) provide three equations for the four unknowns, v_{1fx}, v_{1fy}, v_{2fx}, and v_{2fy}. This along with a fourth equation specifying the outgoing angle:

$$\theta_{1f} = \tan^{-1}\left(\frac{v_{1f_x}}{v_{2f_x}}\right) \tag{11}$$

permits the determination of the values of the four unknowns.

7.8.2 Procedure for Elastic Collision Simulation

Equal Masses

- Place a fresh sheet of white paper on the air table and place two magnetic pucks without Velcro strips on the sheet.
- Aim the projectile puck to create a collision that, for ease of analysis, is not head-on.
- Repeat the collision procedures from part 7.8.1 under Equal Masses

Unequal Masses

- Put a lead collar on the target puck and repeat the above procedure.

7.8.3 Analysis of the Puck's Trajectory

- Follow the procedure in part 7.6.3

7.8.4 Data Collection and Analysis

Note: for ease draw an x-axis along the initial direction the projectile puck. Use equations (3) and (8) through (11) to aid your analysis.

Equal Masses

Initial

Puck #1 $\overline{\Delta x}$ = ______

v = ______

$|p|$ = ______

KE = ______

p_x = ______ p_y = ______

Final

Puck #1 $\overline{\Delta x}$ = ______

v = ______

$|p|$ = ______

KE = ______

p_x = ______ p_y = ______

Puck #2 $\overline{\Delta x}$ = ______

v = ______

$|p|$ = ______

KE = ______

p_x = ______ p_y = ______

Q11)How well are the before/after *x* and *y* momentum components conserved?

Unequal Masses

Initial

Puck #1 $\overline{\Delta x}$ = ______

v = ______

$|p|$ = ______

KE = ______

p_x = ______ p_y = ______

Final

Puck #1 $\overline{\Delta x}$ = ______

v = ______

$|p|$ = ______

KE = ______

p_x = ______ p_y = ______

Puck #2 $\overline{\Delta x}$ = ______

v = ______

$|p|$ = ______

KE = ______

p_x = ______ p_y = ______

Q12) How well are the before/after *x* and *y* momentum components conserved?

Q13) How does the unequal mass affect the momentum and kinetic energy of the pucks?

Q14) Explain your results, is this what you expected? Why? Make sure to explain any discrepancies between your data and your expectation.

7.9 Conclusion

Analyze the similarities and differences between the explosion, the inelastic collision, and the elastic collision. Focus on the how well kinetic energy and momentum are conserved. Explain the effects of any experimental errors.

Appendix A-2

4 VECTORS AND FORCES

4.1 **Purpose:** To perform an Exercise in Adding Vectors and Introduce the concept of Forces

4.2 List of Equipment

- Force Table
- Masses
- Balance
- Protractor
- A piece of string 50 centimeters long

4.3 Vectors

A vector is probably the most frequently used entity in physics to characterize space. It can represent the spatial behavior of many things: electric and magnetic fields, fluid flows, mechanical forces, velocities and accelerations.

For an N dimensional space, a vector is an array of N numbers. For example, a vector representing a point in a plane ($N = 2$) can be expressed using two quantities: the point's distance from an origin, r, and its angle, θ.

In this lab we will model an $N = 2$ system having multiple forces. The forces will be such that they add to 0. There will be no system motion because the system is in static equilibrium.

4.4 The Force Table

The model itself will be a force table. As mentioned above, it will study planar (two-dimensional) force vectors in static equilibrium. The force table consists of a circular metal disk having a calibrated angular scale. Three masses, m_i, are suspended from the disk's rim with strings. The three strings are tied together at the center of the disk. The masses and/or angular positions of the strings are adjusted until the three mass + string system is in static equilibrium. See Figure 1.

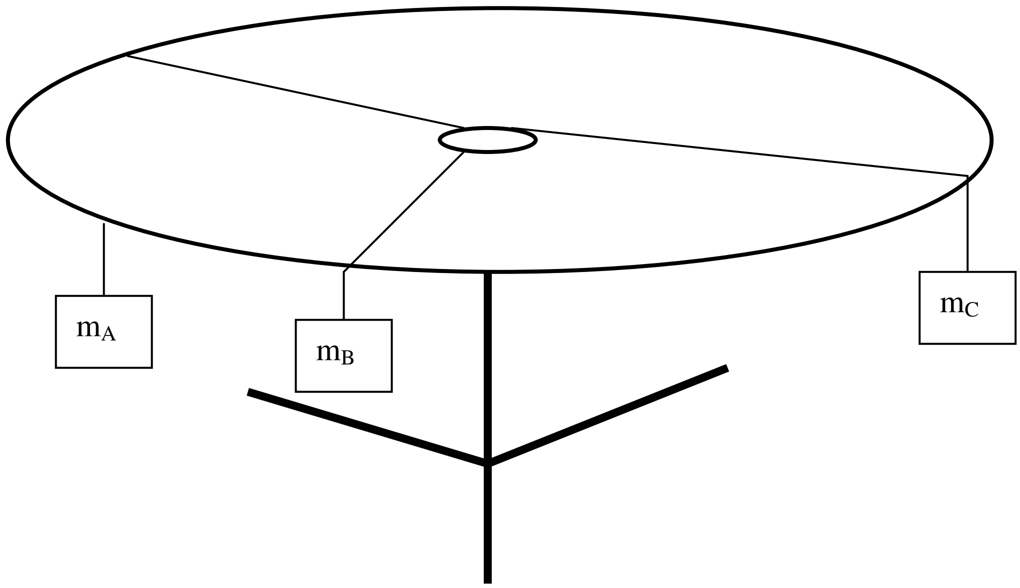


Figure 1: The Force Table

The force acting along the *ith* string is proportional to the mass hung from that string, $m_i = m_{A,B,C}$, since

$$\left|\vec{F}\right| = m_i g, \qquad (1)$$

where g = 9.8 m/s^2. The total force is the vector sum of the three string forces:

$$\vec{F}^{tot} = \sum \vec{F}_i \qquad (2)$$

By varying the masses and the directions of the strings, $\vec{F}^{tot}$ can be adjusted to zero and the string system will be in static equilibrium. At equilibrium, the ring will be suspended about the table's center pin without touching it. The resulting force acting on the ring is:

$$\vec{F}_{tot} = \vec{F}_A + \vec{F}_B + \vec{F}_C = 0 \qquad (3)$$

There are two techniques for calculating $\vec{F}^{tot}$:

1. Calculate the x,y components of the forces
2. Draw vectors representing the three forces and add them using parallelograms. Because of the very basic and unsophisticated nature of this method, this lab will focus primarily on the first technique.

The x and y components are given by:

$$\begin{aligned} F_x^{tot} &= \left|\vec{F}_A\right|\cos\theta_A + \left|\vec{F}_B\right|\cos\theta_B + \left|\vec{F}_C\right|\cos\theta_C \\ F_y^{tot} &= \left|\vec{F}_A\right|\sin\theta_A + \left|\vec{F}_B\right|\sin\theta_B + \left|\vec{F}_C\right|\sin\theta_C \end{aligned} \tag{4}$$

where θ_A is the angle as measured on the force table's circular angular scale between the direction of the A string and the chosen x-axis.

To compute $\vec{F}^{tot}$ by the addition of x,y components, choose an x,y coordinate system that simplifies subsequent calculations—e.g. have the x-axis aligned along the direction of one of the three forces.

4.6 Experimental Procedure

We will use the force table to obtain static equilibrium in two situations:

1. By varying the values of masses which have been positioned at fixed angles.
2. By varying the angles of fixed masses.

4.6.1 Angles and 2 masses fixed

- Set up the force table with String A positioned at 45°, String B at 120°, and String C at 270°.
- Your TA should have provided you with two masses. Consider one of them to be m_A and the other m_B, and record their values below:

  m_A = _____________________

  m_B = _____________________

- Place m_A on String A and m_B on String B.

- Using equations (1), (3), and (4) above, determine the necessary m_C to make this system reach static equilibrium. Record your calculations and answer below.

m_C = ____________________

- Check your answer by placing your calculated value for m_C at on String C.

Question 1: Is your system at stable equilibrium? If not, what should you have done to reach static equilibrium?

4.6.2 Masses and 2 angles fixed

- Set up the force table with String A at 120° and String B at 270°.
- Determine a system of masses to use so that $m_A = m_B = 2m_C$. Record your masses below.

m_A = ____________________

m_B = _____________________

m_C = _____________________

- Using Equations (1), (3), and (4), determine where String C should be to make the system in stable equilibrium.
- Record your calculations and answer below.

String C = __________________

Question 2: Was your result correct? Why or why not?

4.6.5 Using Vectors to Problem Solve

Your TA will give you a slip of paper with a starting point and an ending point of two places in Small. You and your partner will measure the distance between these two points using only the 50 centimeters of string and a protractor. Apply what you learned about the addition of vectors, making sure to keep careful note of the horizontal and vertical distances as you add them.

Appendix A-3

8 CONSERVATION OF ENERGY—BLOCK VS. DISK ON TRACK

8.1 Purpose: To highlight the difference between translational and rotational motion while demonstrating the conservation of energy in the presence of one or both of those.

8.2 List of Equipment

- Data Studio
- Inclined track
- Calculator
- Aluminum disk mounted on small axle
- Wood blocks
- Calipers
- Assorted measuring tools (ruler, protractor, etc.)

8.3 Energy of Motion

In this lab, we will study energy conservation for both translational and rotational motion. Translational motion occurs when the center of mass of the object moves, while rotational motion is when the object moves around its center of mass. A spinning top, for instance, will have rotational motion, while a running man will have translational motion. If only translational motion is present, then the kinetic energy, as we have previously learned, will be

$$K = \frac{1}{2}Mv^2 \tag{1}$$

where K is the total kinetic energy, M is the mass of the body, and v is the velocity of the center of mass. As has been demonstrated, this equation is used in situations where objects move without rotation.

However, when rotation is added plays a factor in the movement of the object, the kinetic energy produced by the rotation must be added to Equation 1. In that case,

$$K = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2 \tag{2}$$

Now, I is the moment of inertia for the rotating object and ω is the object's angular velocity about its center of mass. It should be noted that Equation 2 is only useful when the two terms are linked or correlated to each other—as in, the velocity and angular velocity are related to each other by some linear equation and relationship. If there is no correlation, Equation 2 may not be used. In this lab, because the rotation of the wheel is linked to the translational velocity of it sliding down the track, Equation 2 may be successfully utilized. Since the rotating object in this lab is a disk, it is relevant to know that, for a uniform disk with a radius of R,

$$I = \frac{1}{2}MR^2 \tag{3}$$

Therefore, for a disk rolling down a track, the total kinetic energy may be defined as

$$K = \frac{1}{2}Mv^2 + \frac{1}{4}MR^2\omega^2 \tag{4}$$

8.4 Block Sliding Down Inclined Track

Unlike a rolling disk, a sliding block has only one source of kinetic energy—translational kinetic energy, so we use Equation 1.

Conceptual question to answer in lab report: If a block and disk of the same mass are released from identical heights on identical inclined planes, which will have the faster velocity at the end of the track, assuming no energy is lost to friction?

The potential energy of the block at the top of the track (height h_o) must equal the kinetic energy of the block at a later section of track (height h), according to the law of conservation of energy. Therefore, we use Equation 1 and the conservation of energy to find that

$$Mgh_0 = Mgh + \frac{1}{2}Mv^2 \tag{5}$$

Solving Equation (5) for v, we determine that

$$v = \sqrt{2g(h_o - h)} \tag{6}$$

8.4.1 Experimental Procedure for Block Sliding Down Inclined Track

- Using a step shim, adjust the incline of the track so your calculator slides down the track at a steady rate. You may need to place some wooden blocks under the step shim to increase the incline of the track. (Note: there will be some energy lost to friction in this experiment, but we will assume that it is minimal.)

- Measure the length of the track, L, and the maximum height, h_o, of the track (i.e., where the wheel starts its descent down the track.) Also pick a point about 3 inches from the motion sensor at the bottom of the track. This will be the endpoint of your calculator's journey down the track, and its final height, h. (Note: this point may have to be adjusted later depending on your calculator's movement.)
    - L = ______________________________
    - h_o = ____________________________
    - h = ______________________________
- Measure the mass of the block.
    - M = ___________________________
- Open the Data Studio Program.
- Attach the motion sensor to Digital Channels 1 and 2 of the Science Workshop 750 box. Make sure that the yellow plug is in Channel 1 and the black plug is in Channel 2.
- Add the motion sensor to the Data Studio program by clicking on the "Add Sensor or Instrument" tab in the Experiment Setup window, and selecting the motion sensor icon under the digital sensors. The motion sensor icon should appear in the experiment set up window under the digital channels 1 and 2.
    - *Note*: You could also add the motion sensor simply by double-clicking on Digital Channel 1 and selecting the motion sensor from that list.
- Under measurements, select position and velocity only, and that the sample rate is 10 Hz.
- Under the Sampling Options tab, select the automatic stop time to be 10-15 seconds. You may need to decrease or increase this time later, depending on how fast your calculator moves along your track.
- In the bottom half of the Experiment Setup window, select the motion sensor tab. You should hear a clicking sound as the motion sensor begins taking measurements.
- Release the disk and press start to begin collecting data.
- Under the Display window, click the graph window and select the Position for Run 1. A graph titled "Graph 1" should appear. You can rename it by double-clicking on the Graph 1 icon in the Display window.
- Double click on the graph window. Under the Tools tab, select "Curve fit" and then hit Ok. This should put a "Fit" button on the Graph toolbar. Under this button, select "Quadratic Fit." Another line should appear on your graph, as well as some information about this line of best fit.
- Click the Σ button, and select the minimum, maximum, mean, and standard deviation values, as well as the "Show all" option.
- Rearrange these boxes as needed so they do not disrupt the graph, and then print.
- Repeat with the velocity graph.
- Compare the experimental value of velocity to that obtained from Equation (6).

Questions to consider in lab report:

How accurate was the experimental value of velocity? Perform error analysis, and discuss what accounts for any error in your result compared to the expected value?

Did the velocity of the block increase as it slid down the track? Why or why not?

How would your results have differed if the track was higher or tilted at a more severe angle?

8.5 Disk Rolling Down Inclined Track

When a disk rolls down a track, it has, as noted above, two components to its kinetic energy: rotational and translational. These two components are linked because it is the rotation of the disk on its axle that causes the disk to translationally move down the track without slipping. We furthermore know that the quantities v *and* ω are linked by the property

$$v = \omega r \qquad (7)$$

Note the difference between the "r's": R is the radius of the disk itself, while r is the radius of the axle.

When the disk is at the highest point of the track, before it begins to roll, it has no kinetic energy; all its energy is stored as potential energy according to the equation

$$E_{TOT} = Mgh_o \tag{8}$$

As the disk begins to roll, some of this initial potential energy is converted into kinetic energy as described by Equation (8) above. The resulting energy, then, is

$$E_{TOT} = Mgh + \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2 \tag{9}$$

Equation (3) gave us a value for *I* for a disk. Plugging that value into Equation (9), we determine that

$$E_{TOT} = Mgh + \frac{1}{2}Mv^2 + \frac{1}{4}MR^2\omega^2 \tag{10}$$

Substituting Equation (7) into Equation (10) we determine that

$$E_{TOT} = Mgh + \frac{1}{2}Mv^2 + \frac{1}{4}Mv^2\left(\frac{R}{r}\right)^2 \tag{11}$$

From the law of conservation of energy, we know that Equation (11) must equal Equation (8). After simplifying, we determine that

$$g(h_o - h) = v^2\left[\frac{1}{2} + \frac{1}{4}\left(\frac{R}{r}\right)^2\right] \tag{12}$$

By rearranging and simplifying, we can determine the velocity of the rolling disk to be

$$v = \sqrt{\frac{4g(h_o - h)}{2 + \left(\frac{R}{r}\right)^2}} \tag{13}$$

8.5.1 Disk Rolling on Track Experimental Procedure

- Using the step shim, adjust the height of the inclined track so that the disk rolls smoothly and steadily down in a straight line. (If necessary, place a textbook or other object under the step shim to increase the initial height.) Make sure the wheel does not scrape the sides of the track. The maximum height and length of the track should be same as the last section, but you may want to pick a different ending spot (and height) for the disk.

    - L = ______________________
    - h_o = ______________________
    - h = ______________________
- Measure the mass of the disk.
    - M = ______________________
- With calipers, measure the radii of the disk (R) and of its axle (r).
    - R = ______________________
    - r = ______________________
- Under the Sampling Options tab, select the automatic stop time to be 20 seconds. Again, this time may be adjusted if needed.
- Release the disk and press start to begin collecting data.
- As in the previous section, prepare and print the position vs. time and velocity vs. time graphs using the data collected for the disk rolling down the track.
- Compare the experimental value of velocity to that found in Equation (13).

Questions for the lab report:

What, if anything, was different about the velocity of the disk compared to the velocity of the "block?" Explain any differences.

How accurate was the experimental velocity compared to the theoretical value? What was the level of error, and what were possible sources of error?

What would have happened to your results if you had used a disk with a smaller radius? A disk with a larger axle?

Appendix A-4

3 MOTION WITH CONSTANT ACCELERATION

Purpose:
Study and understand how objects move under constant acceleration in one and two directions.

3.1 List of Equipment:

- Ball
- High speed camera
- Strobe light
- Kinematics Manipulator computer program

3.2 Motion with Constant Acceleration: One Dimension

Lab 2 showed that the motion of objects in free fall can be described by the kinematics equations:

$$v_y = v_{y_0} + a_y t \tag{1}$$

$$v_y^{\,2} = v_{y_0}^{\,2} + 2a_y(y - y_0) \tag{2}$$

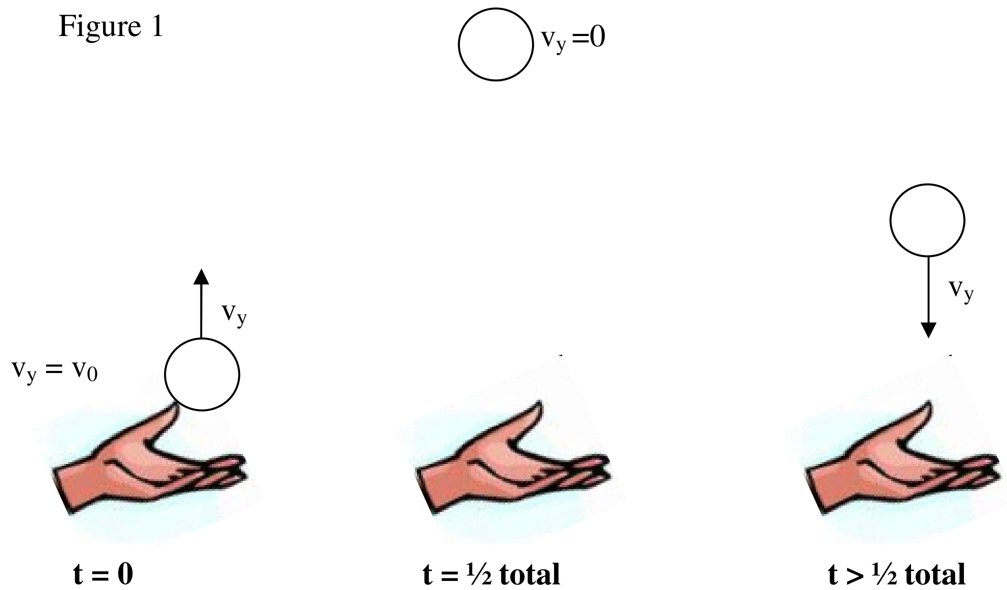
$$y = y_0 + v_{y_0} t + \frac{1}{2} a_y t^2 \tag{3}$$

where y is the position of the object at the time, t, y_0 is the initial position of the object at t = 0, v_y is the velocity of the object at the time, t, v_{y_0} is the initial velocity of the object, and a_y is the objects acceleration.

Free fall is a term for objects that are moving with constant acceleration due to the force of gravity. Free fall is a special case of motion with constant acceleration, but the kinematics equations used to describe free fall motion also describe the motion of *any* object under constant acceleration. This includes objects moving in one, two, or even three dimensions.

Observing motion with constant acceleration is common in daily life. A ball that has been tossed straight up in the air is an example of motion with constant acceleration one dimension. (Figure 1) When tossing a ball, the toss gives it an initial force upward (in the positive y direction) which means that it has an initial *velocity*, $v_0 = v_y$, in that direction.

Figure 1



The ball, like the free fall object in Lab 2, also has a constant acceleration due to gravity. The deceleration due to gravity causes the ball's upward (y direction) velocity to become slower and slower until it has a velocity, $v_y = 0$. At this point the ball falls just like an object in free fall.

Q1. What is the acceleration of the ball when it reaches its highest point?

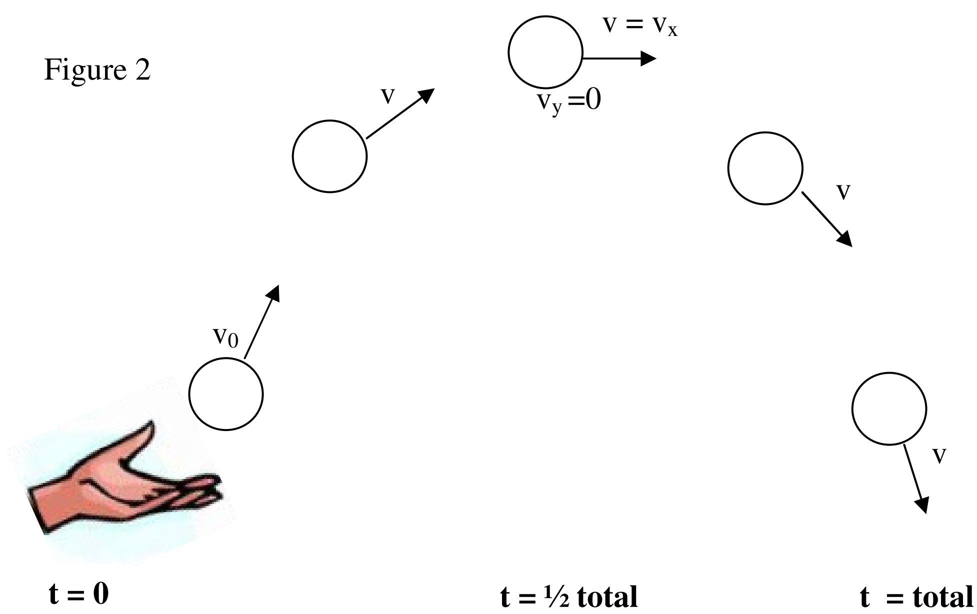
Q2. What is it's velocity at the highest point?

3.3 Motion with Constant Acceleration: Two Dimensions

Similar to the ball that is tossed straight up, a ball that is thrown is an example of motion with constant acceleration in two dimensions. (Figure 2) The throw gives the ball an initial force upward (in the positive y direction) *as well as* a force outward (in the positive x direction), so the ball has an initial velocity, v_0, with components in both directions v_x and v_y.

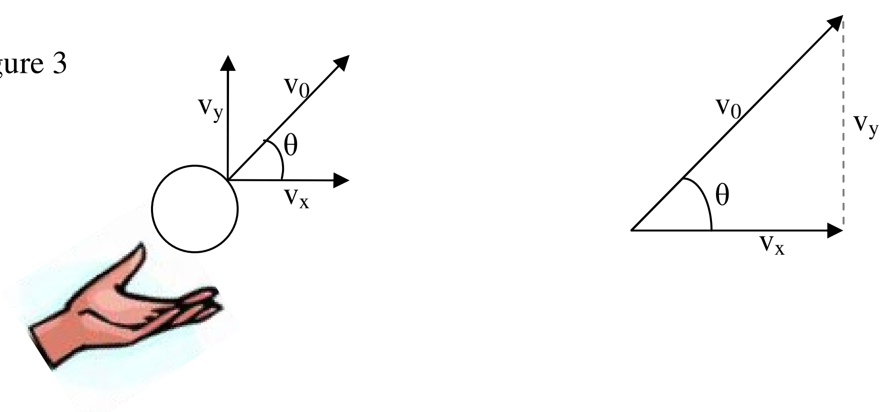
Q3. How does the acceleration in the x direction affect the path of the ball?

Figure 2



The initial velocity in each direction can be found by breaking the initial velocity vector down into its horizontal and vertical components. (Figure 3)

Figure 3



The value of the x and y components of the velocity are found by using the equations:

$$v_y = v_0 \sin(\theta) \qquad (4)$$

$$v_x = v_0 \sin(\theta) \qquad (5)$$

where v_0 is the initial velocity, θ is the angle between the direction of the initial velocity and the horizontal, v_x is the velocity in the x direction, and v_y is the velocity in the y direction.

Using Pythagorean Theorem we can also find the magnitude of the initial velocity by working with its x and y components:

$$|v| = \sqrt{v_{x_0}{}^2 + v_{y_o}{}^2} \qquad (6)$$

Similarly, the angle the ball is throw at can be found with the equation:

$$\tan(\theta) = \frac{v_{y_0}}{v_{x_0}} \qquad (7)$$

In order to analyze the motion of the ball we must examine each dimension separately. The motion of the ball in the x direction does not affect the motion of the ball in the y direction.

Q4. How does the ball's motion in the y direction in the two dimensional example compare to the ball's motion in the one dimensional example?

Because the force of gravity is entirely vertical, it only creates a deceleration downward (in the negative y direction). Therefore the motion in the x direction has an acceleration, $a_x = 0$.

Q5. What is the ball's velocity in the x direction if it has an initial x velocity of .25m/s?

Q6. Why?

3.4 Procedure

- Follow your lab TA's instruction on how to take an extended exposure photo of you and your partner throwing a ball to one another. (For the best results throw the ball high into the air to get a longer arc. This will provide you with more points for analysis)
- Open the Kinematics Manipulations program on your computer.

- Import your photo into the program.
- Open the photo in the program window and click on each point in the photo where you see the ball, beginning with the first point you see after the ball left the thrower's hands
- Create the scale in meters using the tool in the toolbar.
- Create a best fit line for the ball's path using the regression tool in the toolbar

3.5 Analysis

- Use the Kinematics Manipulations program to find the ball's initial velocity, v_0 and the initial angle of the throw, θ.
- Start by finding the initial velocity in the x and y directions, v_{x_0} , and v_{y_0} .
    - o Hint: You can find the ball's highest point by finding the maximum of the best fit line using the tool in the toolbar.
- Choose the equation you want to use by clicking on it.
- Rearrange the equation by clicking on the variable you want to solve for.
- Make sure to enter all the pertinent information you know in the boxes next to the variables and press solve.
- Use the components of velocity in equations (6) and (7) to find the ball's initial velocity, v_0 and the initial angle of the throw, θ.
-

3.6 Conclusions

Q8. How does the velocity and angle calculated compare with your expectation of the values based on looking at the photo?

Q9. Explain any errors that may have occurred.

Appendix B
Student Survey

For the first 5 questions please answer using a 1-5 scale where 1=very good, 2=somewhat good, 3=neutral, 4=somewhat bad, and 5= very bad

1) How was the layout of this lab compared to other labs you have done?

2) How clear were the procedures?

3) How did the order that the information was presented in aid your understanding of the lab?

4) How clear were the informational sections compared to other labs you have done?

5) How effective were the data and analysis sections in aiding your understanding of the material?

What were the concepts taught in this lab?

What parts of the lab did you like?   Why?

What parts of the lab did you like the least?   Why?

Is there any part of the lab that you feel is ineffective, confusing, or unnecessarily complicated?

Do you have any suggestions?

Appendix C – The survey results from lab 7

Appendix C-1 – The quantitative results

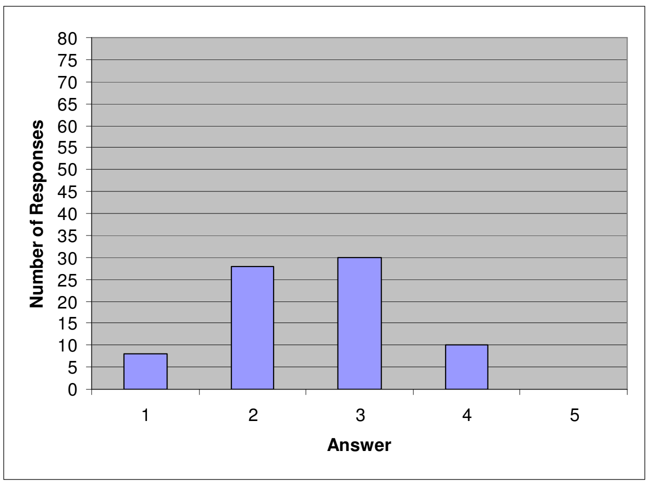
In the figures that follow the graph (a) shows survey responses from the control, graph (b) shows the cumulative trial results, and graph (c) shows the results from trial 3 only. Trial 3 was selected because it tested the final and most refined version of the lab.

Figure 1

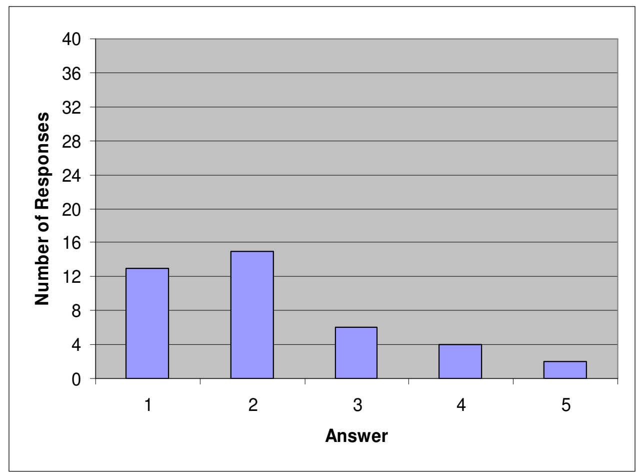
Response to Question 1:

How was the layout of this lab compared to other labs you have done?

a)



b)



c)

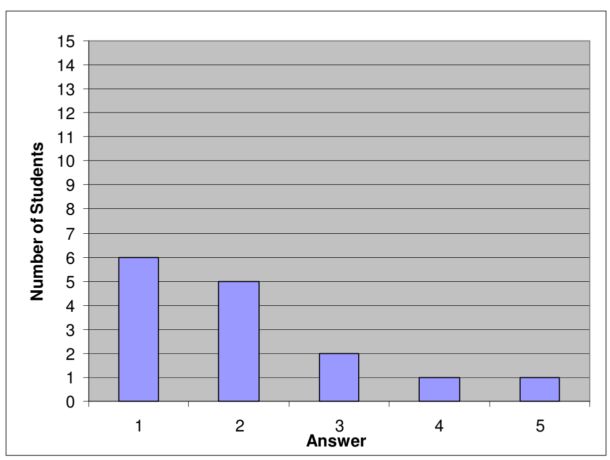
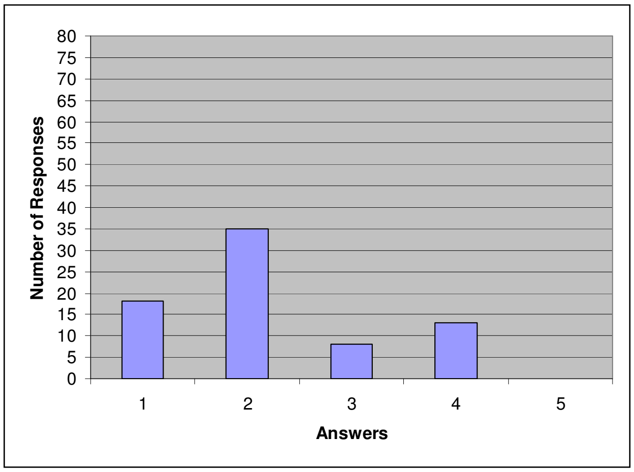
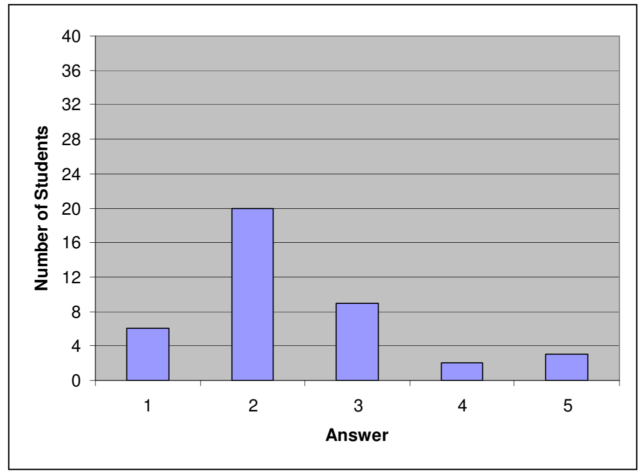


Figure 2
Response to Question 2:
How clear were the procedures?

a)



b)



c)

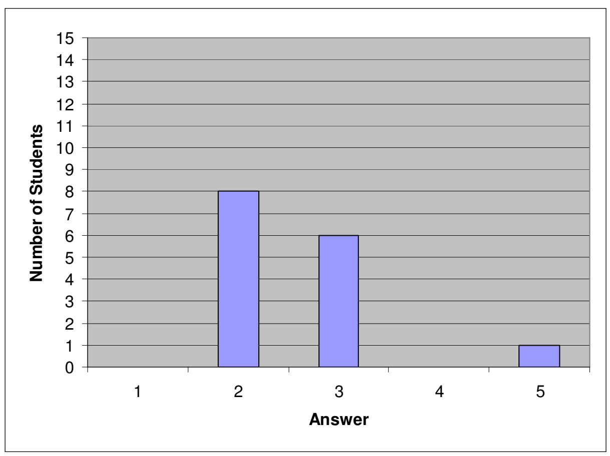
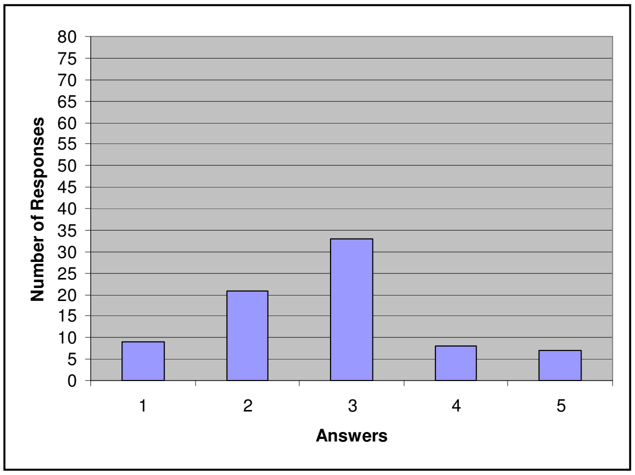
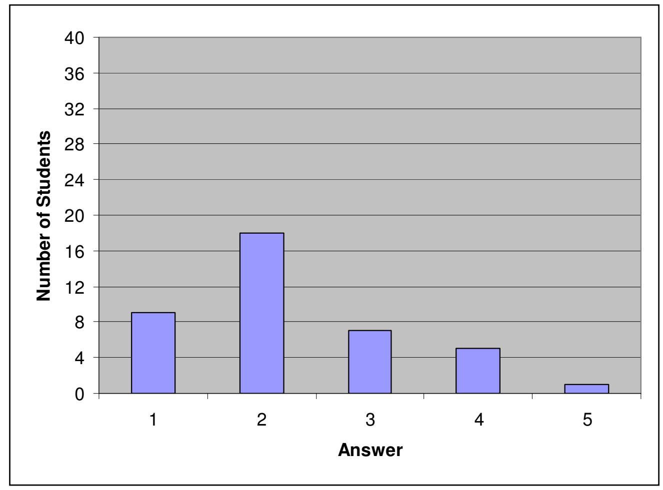


Figure 3
Response to Question 3:
How did the order that the information was presented in aid your understanding of the lab?

a)



b)



c)

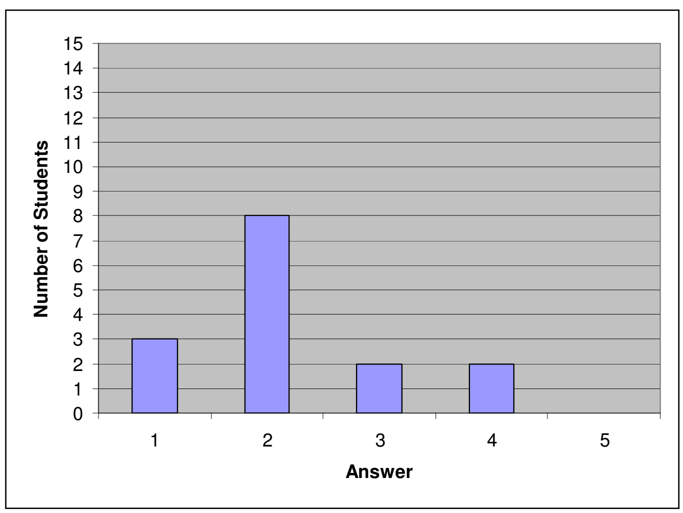


Figure 4
Response to Question 4:
How clear were the informational sections compared to other labs you have done?

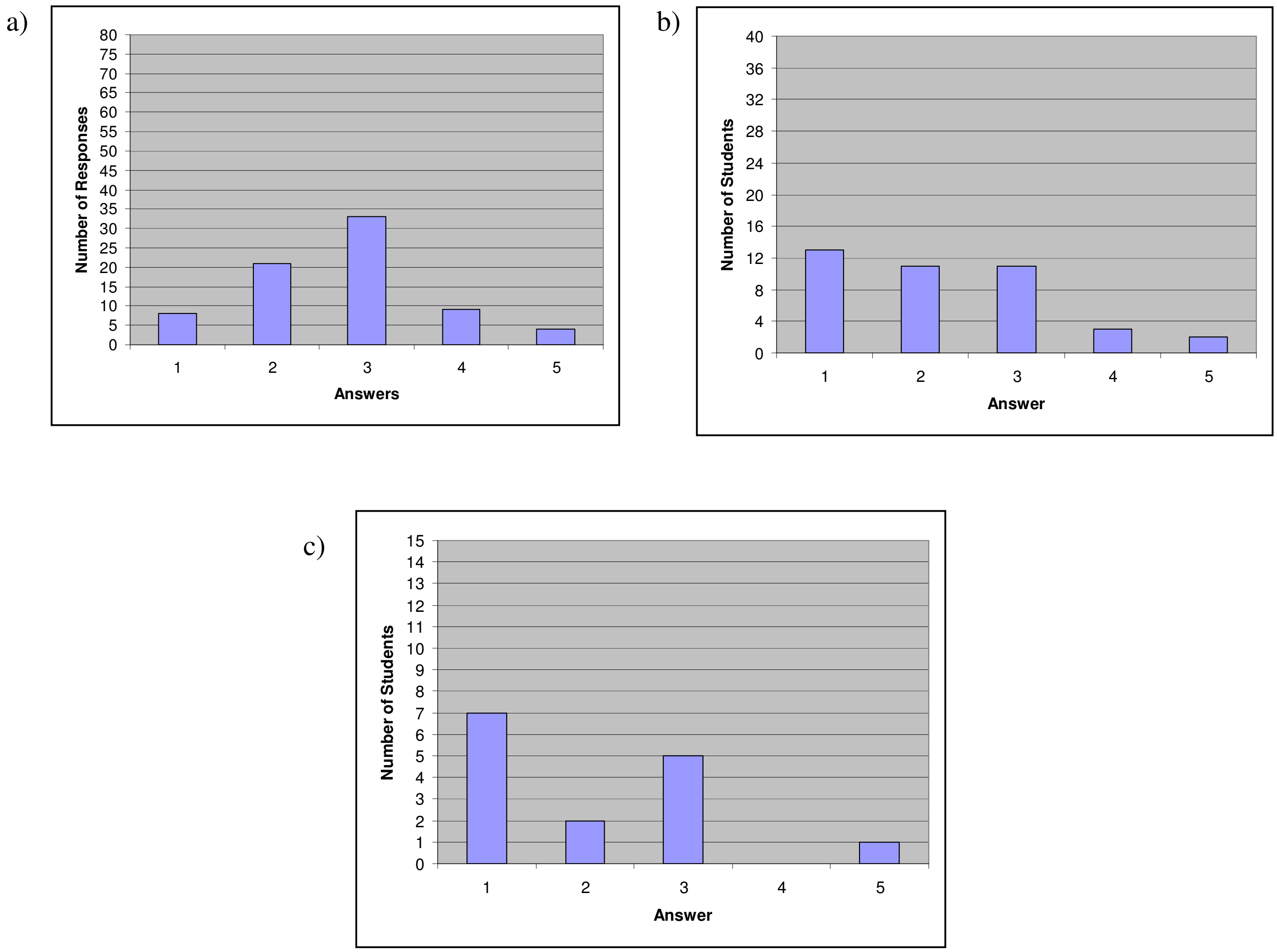
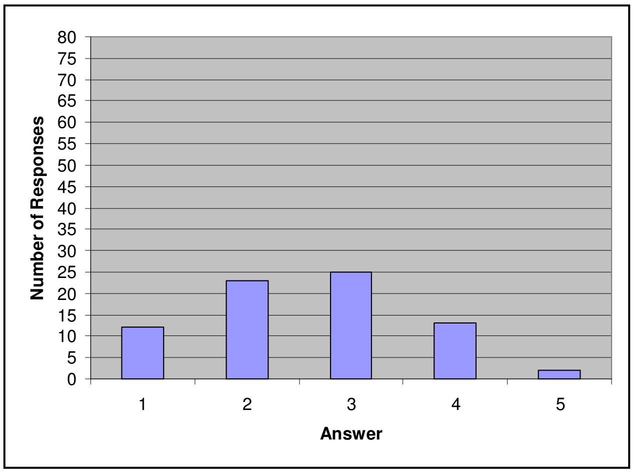
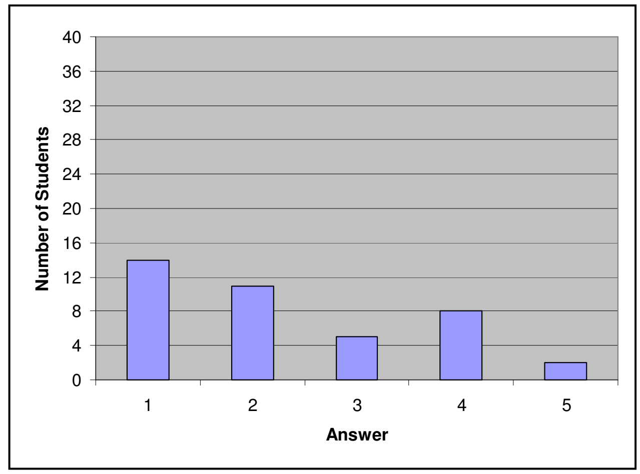


Figure 5
Response to Question 5:
How effective were the data and analysis sections in aiding your understanding of the material?

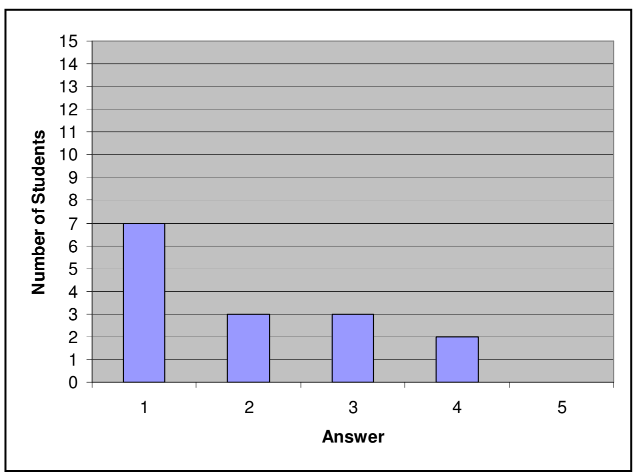
a)



b)



c)



Appendix C-2 – The qualitative comments from lab 7.

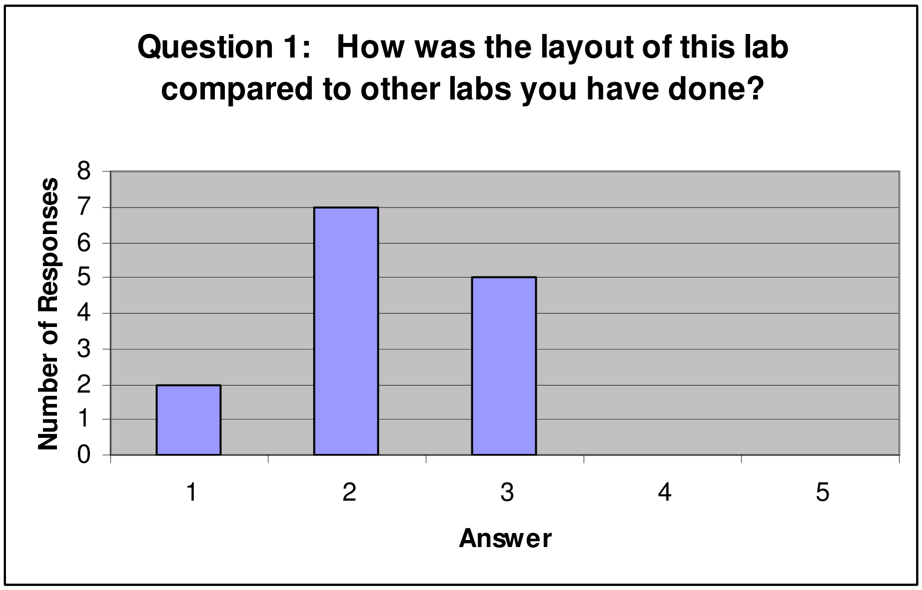
The comments for each trial are listed in order of frequency. If the comment was received more than once the number to the right indicated how often it was received in that trial.

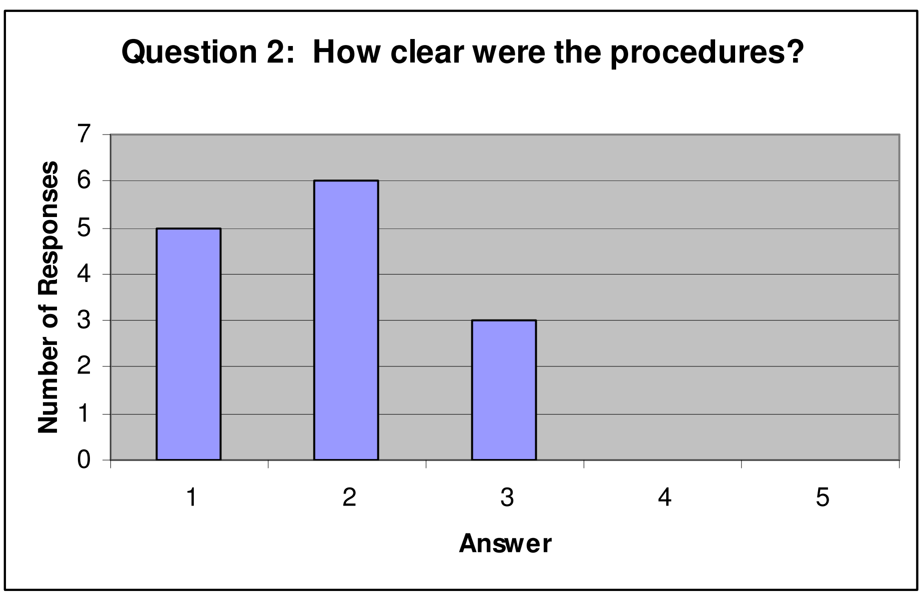
Negative feedback		Positive feedback	
Trial 1			
Placement of the analysis directions confusing	5	Procedure clear	4
Need a definition of momentum	3	Fill in sections were helpful and clear	2
Too long	3	Ruler track is helpful	2
Slow movement in the explosion, rubber band		Concept questions aid understanding	
Ruler track hard for only two people		Information sections were helpful	
Conservation question confusing		Style aided comprehension	
Need to reference formulas in analysis section			
Trial 2			
Too long	10	Easy to understand	
Analysis is repetitive/Measurement is tedious	2	Concept questions aid understanding	4
Do not like concept questions	2	Style aided comprehension	3
Need better instruction for inelastic analysis		Fill in sections were helpful and clear	2
Need a definition of momentum		Information sections were helpful	
Prefer a lab report		Liked use of rubber band	
Layout is bad			
Trial 3			
Analysis is repetitive /Measurement is tedious	9	Fill in sections were helpful and clear	5
Too long	4	The procedures are clear	4
Need more time to think for concept questions	2	Style aided comprehension	4
Did not like analysis/conclusion questions		Concept question aid understanding	3
		Informational sections were helpful	2
		Easy to understand	2

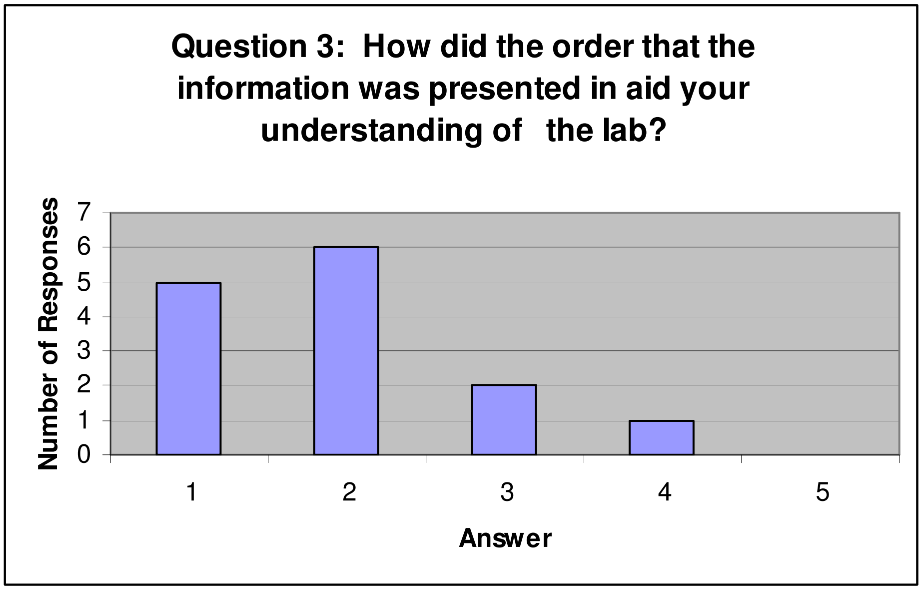
Control			
Analysis is repetitive/Measurement is tedious	33	Procedures are clear	4
Informational section are unclear	15	Analysis questions were clear	3
Lab report is not helpful/ purpose unclear	13	Informational sections were clear	2
Data analysis procedure was confusing	12		
Style/format was confusing/complicated	5		
Difficult to align pucks for collision	3		
Need data studio directions	2		

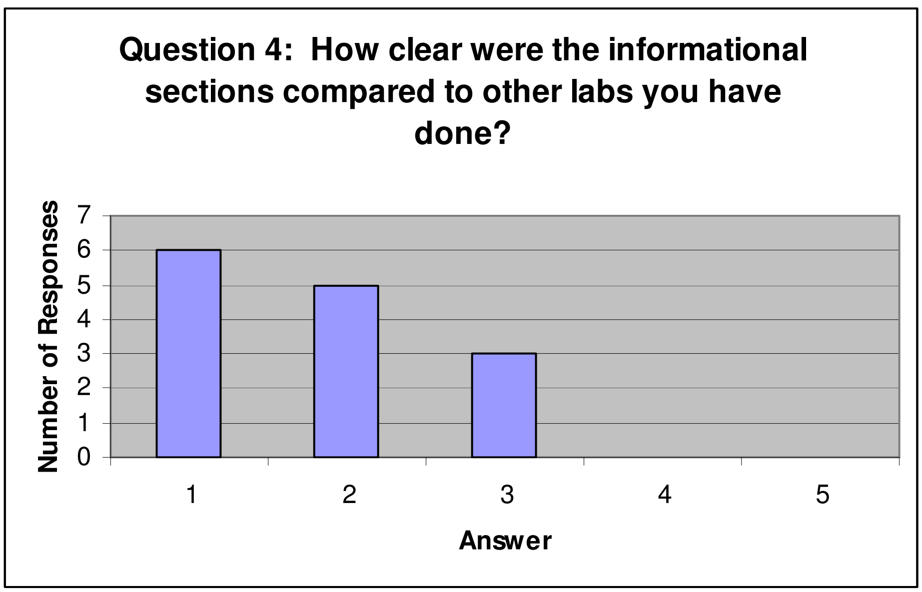
Appendix D – The survey results from lab 8

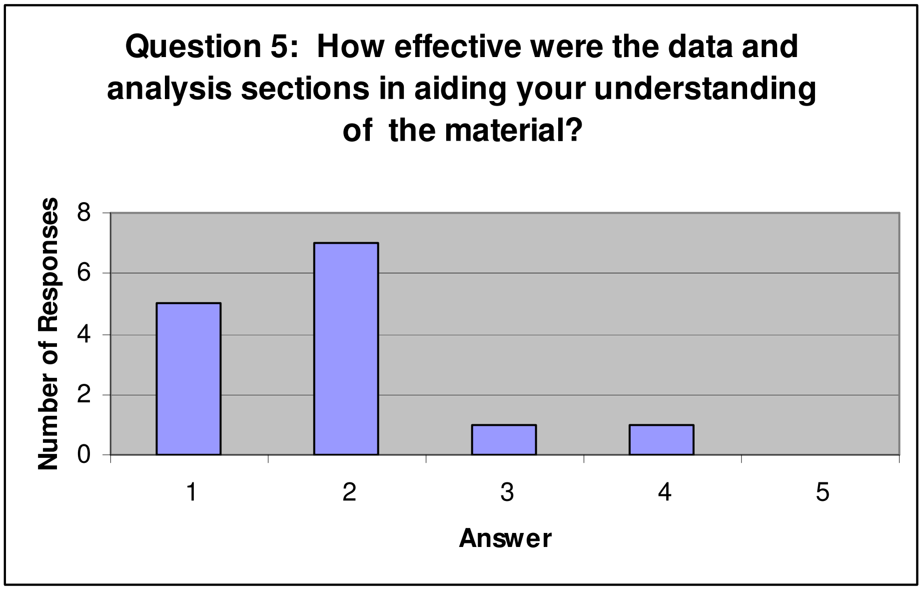
Appendix D-1 – The quantitative results from lab 8






Question 3: How did the order that the information was presented in aid your understanding of the lab?
Number of Responses
0
1
2
3
4
5
6
7
1
2
3
4
5
Answer


Question 4: How clear were the informational sections compared to other labs you have done?
Number of Responses
0
1
2
3
4
5
6
7
1
2
3
4
5
Answer



Appendix D-2 – The qualitative comments from lab 8

Problems		Positive feedback	
Need a uniform block/ block with less friction	10	Easy to get data for rotation	6
Need to clarify data studio directions	2	Liked the use of data studio for results / good data studio instructions	2
Want blanks to fill in velocities		Like the slots for recording data	2
High error with plotting the data		Data analysis was clear	2
Use the same angle for both parts of the exp.		The translational part was interesting	
Don't like using data studio		It's better then the original lab	
Clarify that time ends after object gets down the track		Concept questions help focus the lab	

Appendix E – The computer program for lab 3

Appendix E-1
Kinematics Manipulator Program Requirements

- It should allow user to import a photo as input.
- The photo should be displayed on the screen
- There should be a tool bar where the user can chooses a pointer
  - When the user chooses the pointer and clicks on the photo it makes that spot a point
  - The user should be able to erase a point
- The program should ask for the user to input the distance between two points to create a scale
  - It should label each point with an (x,y) using the scale after it has been established
  - The first point chosen should be labeled (0,0)
  - If no scale is established it should assume the scale is based on the number pixels
- There should be a function where the user can pull up a screen to make a regression of the points
  - The user should be able to choose from a number of regression options such as
    - y = x
    - y = x^2
    - y = x^3
    - y = ln x
    - y = e^x
  - when the user chooses a regression type the best fit line should be displayed on the screen
- There should be a function which will find the maximum or minimum on the line and give the user the (x,y) coordinates for that point.
- there should be a display along the bottom which displays the kinematics equations
  - It should list all three equations
  - It should ask "What information do we know?" "Hint: choose points we know the most about, like when $v_y = 0$." and list the variables
    - Δy, Δx, t, v_y, v_x, v_{y0}, v_{x0}, a_y, a_x
    - Each should have a space for data input where the user can type in answers and hit submit to enter that data in the computer
- The user should be able to pick one equation and have the data applied to it.
  - When the equation is picked there should be a function "solve for __" to allow the user to see a rearranged version of the equation which has been solved for that variable
  - There should be a function "apply data" which puts the known data in the equation and solves it
    - If there is not enough data a message should say "Error: not enough data. Please enter data into correct variables"

Appendix E-2 – The requirements and a sample run-through for the Kinematics Manipulator computer program for lab 3

Purpose of the Lab: students take a picture of a ball being thrown and use the points along the trajectory to find the initial velocity, v_0.

The computer program will allow a student user to import a digital photo as input. This photo will be displayed on the monitor, as seen in Figure 1.

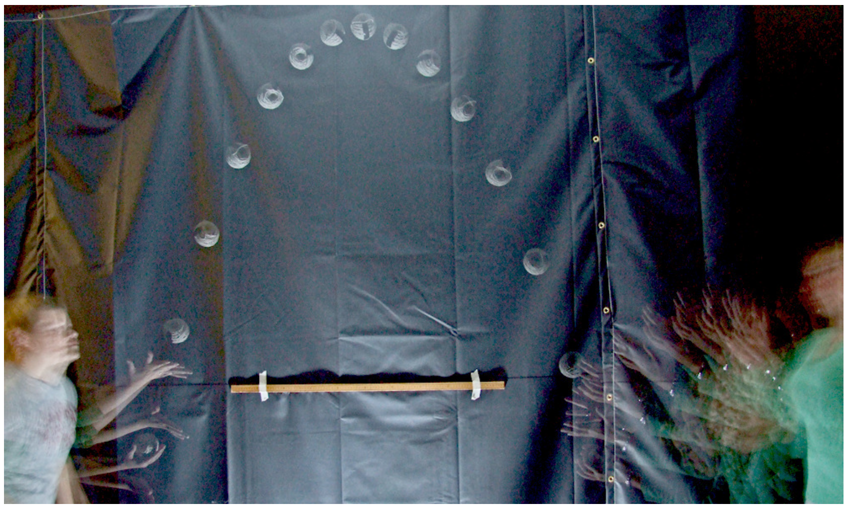


Figure 1

There will be a toolbar where the user can choose a pointer that will allow her to pick a point on the image by clicking on the screen. Using this method, the student will select each point in the image where the ball appears as seen in Figure 2.

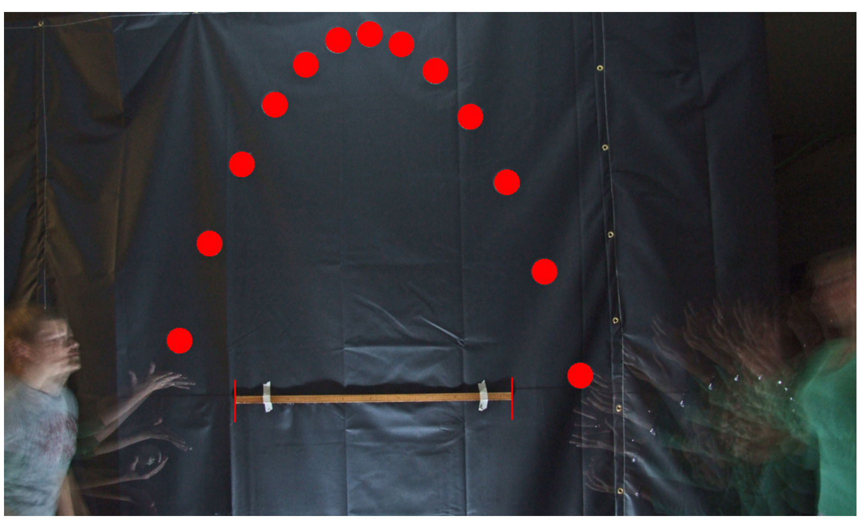


Figure 2

This pointer method will also allow a student to erase the point if she is not satisfied with its placement. The first point, which may be arbitrarily chosen by the student, will be labeled (0,0).

The program will then ask the user to input distance between two arbitrary selected points to create a scale. Each point will be labeled using an (x,y) coordinate system after the scale has been created. If no scale is established, the default scale will be based on the number of pixels in the image.

Another link on the toolbar will allow the student user to list all chosen points on the image in a table, with one column being the x-coordinate and another the y-coordinate.

There will also be a function in the toolbar where the student user can create regression graphs over the ball's trajectory in the image on the screen. The student user must be able to choose from a number of regression options, including:

- y = x
- y = x^2
- y = x^3
- y = x^-1
- y = ln x
- y = e^x

This way, the student user must decide what type of curve the line of best should be. When the user chooses a regression type, the line of best fit will be displayed in a graph on the screen over the digital image of the ball's trajectory as seen in Figure 3. The student then will be able to determine the maximum and minimum points on this line along with their coordinated positions, using a separate tool on the toolbar.

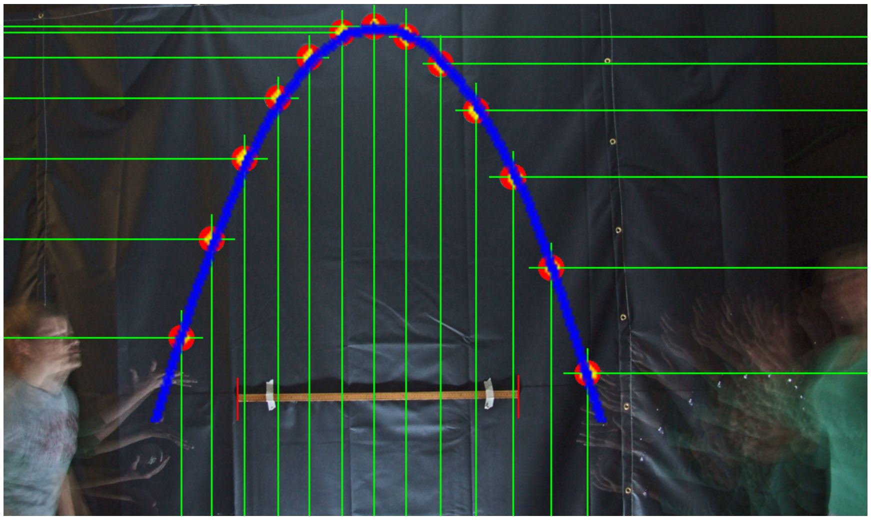


Figure 3

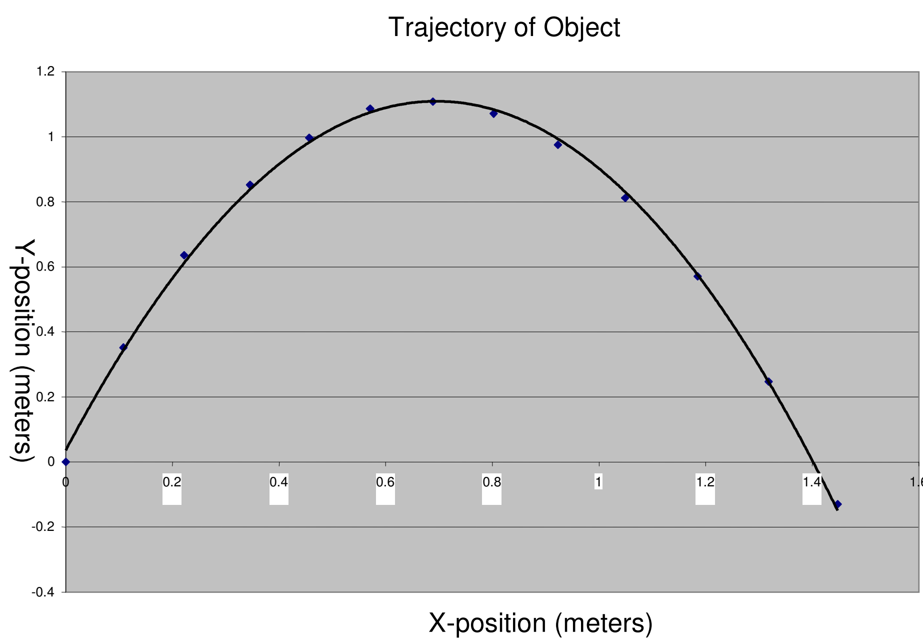


Figure 4

Below the image of the ball's trajectory on the screen, there will be an equations box that will list the three kinematics equations:

$$v_y = v_{y_0} + a_y t \qquad (1)$$

$$v_y{}^2 = v_{y_0}{}^2 + 2a_y(y - y_0) \qquad (2)$$

$$y = y_0 + v_{y_0} t + \frac{1}{2} a_y t^2 \tag{3}$$

for the student's use. The student will select one of the three kinematics equations via a button next to each equation. The student will then be able to select the "Solve for __" function that will allow her to see a rearranged version of the equation which has been solved for that variable. Under the kinematics equations there will be a box which asks:

"What information do we know?

(Hint: choose points we know the most about such as $v_y = 0$.)"

All variables that are part of the kinematics equations will be listed in the box below this question. Next to each variable will be a location for data input so that the user can type data values through the keyboard and submit said data into the computer program. The student can use the "Apply Data" function which will put all known data into the rearranged equation that they have chosen and then solve it. If the necessary amount of data is not provided, an error message will appear that will prompt the user to enter more data.

This program will be used to solve for the ball's original velocity and the angle at which it was originally released. Students will use the kinematics equation function to find the velocity in for the horizontal component and for the vertical component. Then they will have to use this data to find v_0 and θ.

Sample Equation work based on the best fit line from the photo in figures 1-3 as seen in Figure 4:

We found the line of best fit of the trajectory of the object to be:

$$y = -2.2239x^2 + 3.0908x + 0.43477 \tag{4}$$

Using this equation, we found the object's height peaked at the point (0.694930, 1.10867). Using this data and the knowledge that acceleration in the y-direction is simply the acceleration due to Earth's gravity, we used the equation:

$$v_y{}^2 = v_{y_0}{}^2 + 2a_y(y - y_0) \tag{5}$$

The computer program will rearrange this equation to produce:

$$v_{y_0} = \sqrt{v_y{}^2 - 2a_y(y - y_0)} \qquad (6)$$

This equation determines that the initial velocity in the "y" direction of the object, v_{y_0}, is 4.66154 m/s.

To determine the velocity in the x-direction, we first solved for the time it took for the object to reach its peak. To do this, we used the equation:

$$v_y = v_{y_0} + a_y t \qquad (7)$$

The computer program will rearrange said equation to solve for t, so that it becomes:

$$t = \frac{(v_y - v_{y_0})}{a_y} \qquad (8)$$

By substituting in values that we know, we determined that the time it took for the object to reach its peak was t = 0.47567 seconds.

We then used the kinematics equation:

$$x = x_0 + v_{x_0} t + \frac{1}{2} a_x t^2 \qquad (9)$$

to find the initial velocity in the x-direction. Rearranging this equation to solve for the initial velocity in the x-direction, the computer program would then print out:

$$v_{x_0} = \frac{(x - x_0 - \frac{1}{2} a_x t^2)}{t} \qquad (10)$$

Knowing that the acceleration in the x-direction is zero, and substituting in the other values we know, we can determine the initial velocity in the x-direction as 1.36502 m/s.

To determine the initial velocity we substitute the values for the initial velocities in the x- and y-directions into the equations:

$$|v| = \sqrt{v_{x_0}{}^2 + v_{y_o}{}^2} \qquad (11)$$

$$\tan\theta = \frac{v_{y_0}}{v_{x_0}} \qquad (12)$$

Equation (11) gives the magnitude of the initial velocity as 4.85729m/s and equation (12) gives the initial angle of the throw to be 73.67868°.