# Lab Revising 101:
# Revise, Rework, Revamp


A Senior Research Project by:
Jessica Vance

Collaborated with:
Melissa Zoller

Advised by:
Professor Jan Chaloupka



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## Objective and Overview

The objective of this Senior Research Project is to reorganize, rewrite, and reinvigorate the Physics 101 Labs. By improving the organizational structure of the manual, cutting down on superfluous and unnecessary information provided in the laboratory, rewriting current labs, and in some cases creating entirely new labs, we hope to improve the efficiency and effectiveness of the Physics 101 Labs. Laboratory experience and learning is, and should be, an integral part of science education; however, as the labs are presented in the current system, they are not as conducive to student learning as they need to be.

Originally, the intent was to create an entirely new lab manual. However, given the incredibly daunting task that this would entail, it was decided, upon conferring with Professor Chaloupka, that a more readily attainable goal would be to create two original labs and edit two more. I believe we have succeeded beyond anyone's expectations, including my own, in this project. We have rewritten or heavily revised four labs; of those, we have tested two on current Physics 101 students, who then completed surveys that gave qualitative and quantitative responses to the labs.[1] These tests were pertinent to this project because it allowed for additional improvement of the new labs before they were finalized for this project. Moreover, having current Physics 101 students test these labs allowed us to determine what students with similar levels of experience and education in physics would learn from performing these labs. Furthermore, we have outlined the design for a new computer program that would revolutionize how labs are instructed and performed today. We have also succeeded in changing the focus of the labs. No longer are students expected to learn the material after they leave the lab and

[1] See Physics 101 Lab Evaluation, Appendix B.

express it in lab reports. In these new labs, the focus is shifted toward student learning in the laboratory itself, with conceptual questions and room for data analysis and calculations in the manual. This provides students with the opportunity to learn in the lab itself rather than in their dorm rooms.

**Purpose**

According to the current laboratory manual, students perform laboratory experiments because, "by performing hands-on experiments [one is] able to explore and confirm (or disprove) the concepts which scientists have put forth to describe the processes that govern our world."[2] Furthermore, according to John Carnduff and Norman Reid, "the laboratory provides a setting for training not only in practical hand and instrument skills but also for many of the thinking, planning, recording, interpreting and group working skills that a degree course must include."[3] Laboratory experiments should clarify information presented in lecture and further students' understanding of physical concepts, properties, theories, and laws. Indeed, some basic physical ideas—for example, that gravity is a constant on Earth's surface—are not intuitive for the non-scientist. Without laboratory experiments or some other form of visual or physical demonstration, the information is not easily conveyed. The primary focus of an introductory lab class, then, should be the physical activity of performing the lab itself rather than writing the report afterward. Although report writing is a fundamental necessity of scientific research, it should not be the main focus in a beginner lab course.

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[2] *Laboratory Manual: General Physics 101*, The College of William and Mary, 2006, iv.
[3] John Carnduff and Norman Reid. *Enhancing undergraduate chemistry laboratories: Pre-laboratory and post-laboratory exercises*, (London: Royal Society of Chemistry, 2003), ii.

Indeed, "according to the American Association of Physics Teachers, the important goals of introductory physics laboratories should be designing experimental investigations, evaluating experimental data, and developing the ability to work in groups."[4] Although students in a 101 lab setting will not be able to design their own experiments, the labs should provide the mental stimulation necessary for them to come up with further experiments, if they so choose, or at the very least, enable them to transfer the concepts they learn in the lab to their lecture class. Furthermore, the interactive skills learned by working in a group setting, even if with just one other person, are of prime importance to the student's future. A lab, if it is designed well, may help further the critical thinking and communication skills of the students.[5] In order for any of this to be possible, however, the lab manual must be of high quality. Indeed, as A.H. Johnstone, A. Watt, and T.U. Zaman note:

> "there is no point in putting a student into…a lecture course without mental preparation…The student has to be aware of what the lab is about, what the background theory is, what techniques are required, what kind of things to expect in light of the theory, so that the unexpected, when it occurs, will be evident."[6]

The current lab manual, however, fails to reach these expectations and standards. Its language is too formal and hard to read, let alone understand. Rather than encouraging the study of physics, many students are turned away by the dryness of the language. Physics is a very difficult field to study, let alone master. The problem many undergraduates face is that the professors' knowledge of physics is so far beyond their scope of understanding; there is a seemingly impenetrable barrier between what the professor knows and what the student hopes to learn. The manual, as it is currently written, only further exploits such a sentiment. It makes far

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[4] Eugenia Etkina, Sahana Murthy, and Xueli Zou "Using introductory labs to engage students in experimental design," *American Journal of Physics*, 74 (November 2006): 979.

[5] Anne J. Cox and William F. Junkin, "Enhanced student learning in the introductory physics laboratory," *Physics Education* 37, no.1 (2002): 40.

[6] A.H. Johnstone, A. Watt, and T.U. Zaman, "The students' attitude and cognition change to a physics laboratory," *Centre for Science Education* 33, no. 1 (1998): 23-24.

too many assumptions as to what the student knows, and the background information it does provide is written in a way that makes it difficult to understand. Furthermore, the organization of the manual is confusing and, at times, frustrating. Instructions on how to operate equipment, in particular the Data Studio computer program, are scattered throughout the manual. Earlier directions, no matter how helpful or pertinent, are never referenced again. Repeating, or even better centralizing the instructions, would provide students with easier access to them and allow them to better understand how to utilize the equipment. Furthermore, the manual is full of typographical and grammatical errors that can easily be remedied by a good revision, one we hope to have partially provided. Some of the labs are simply outdated; with the current technological improvements, there may be more efficient or effective ways to teach the concepts to students. For that matter, there may also be more creative ways to demonstrate the physical concepts rather than what is currently designed.

The lab manual, furthermore, places far too much focus on the lab report at the expense of the physical concepts themselves. According to the Investigative Science Learning Environment, students learn best when they design their own experiments to investigate phenomena, test explanations of these, and then apply the explanations to realistic problems. Reports, one should note, are not a part of this process.[7] Although lab reports are integral to sharing physics research, they are often impractical at the introductory level. Far too often, students do not understand why they are writing lab reports. Worse still, they get absolutely nothing out of the experience. Lab reports are subjectively graded by teaching assistants (TAs) who all too often put more focus on the format of the report than what the students learn in the lab. Our plan is to incorporate more worksheets into the lab manual that can be completed during the lab period and submitted to the TAs before students leave. Data will still be collected

[7] Etkina, et. al., 979.

and analyzed, calculations performed, and conclusions drawn; the only difference is that students will not have to write lab reports. Furthermore, we have incorporated more questions into the labs to encourage students to think analytically, so as to ensure conceptual understanding and foster critical thinking skills.

The purpose of this project is to remedy the aforementioned problems using the Learning Cycle Model of a Science Lesson, as shown in Figure 1.[8]

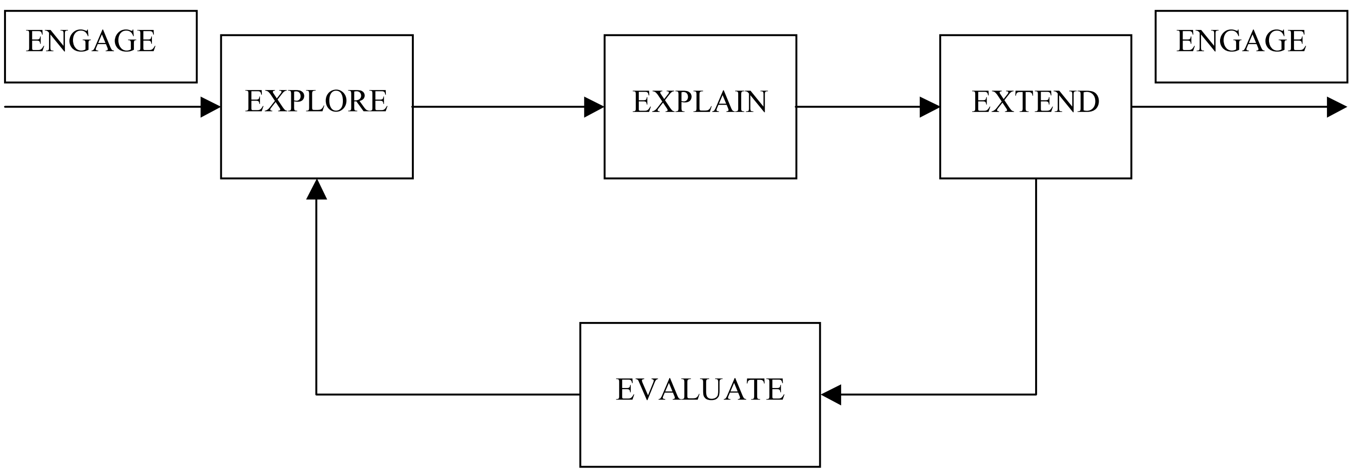


Figure 1: Learning Cycle Model of a Science Lesson

The first step is to engage and motivate students to participate in lab. They will explore options and possible solutions to questions raised in the lab, or questions they brought to the lab session. It is important to note that professors and teaching assistants must decide when to answer a student's question, when to point them in a certain direction, or when to encourage a student to search for the answer on their own. In a lab environment, the student should be encouraged to search for explanations, especially as to how the lab relates to what is taught in

[8] Jane Nelson and Jim Nelson, "Learning Cycle Model of a Science Lesson," *The Physics Teacher* 44 (September 2006): 396-7.

lecture. After all, "definitions and other concepts arise out of the experience rather than from textbook or lecture."[9] Following this process of searching for explanations, students are then encouraged to elaborate (or extend) upon what they have learned by discovering further applications, then evaluate what they have learned before beginning to explore physics again. This step may need to be initiated or instigated by TAs, especially when dealing with reluctant students. Throughout this cycle, students need to be motivated and encouraged to continue their studies. Labs must play a role in this, as they provide the only hands-on method of education provided in a science curriculum. Students must be kept engaged and enthusiastic throughout the process in order for an adequate education to be obtained.

**Achievements**

- **Introductory Sections and General Improvements**

The original lab manual had a very weak introduction section. It was densely and poorly worded and did not adequately convey the purpose of the Physics 101 labs. The new introduction details the importance of physics education and lab experiences in general by describing how the experiences in lab will help prepare students to be better informed and more pro-active citizens in a world that is increasingly becoming scientifically centered.[10] Furthermore, because so many students are inexperienced in writing labs before taking this course, a sample lab format has been added to the text of the manual.[11] It gives the standard layout of a lab write-up, as well as explicit details of what should be included in the report. Each section is explicitly broken-down and its components detailed, as well as what should not be

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[9] Nelson and Nelson, 397.
[10] See Introduction to Physics Labs, Appendix A.
[11] See Lab Format, Appendix A.

included in the report. The purpose of this section is to standardize the reports so that experienced researchers are not given an initial advantage in writing lab reports. To further help with this endeavor, a list of hints about writing the report is also included.[12] These pointers, although obvious and repetitive to experienced lab writers, are designed to help beginning students perfect their formatting skills. Additionally, a section on using Microsoft Excel, at the request of current TAs, will be added, following the advice of TAs that some students do not know how to use this invaluable program.[13]

Additionally, general changes were made to each lab we rewrote. Conceptual questions have become a mainstay in the new labs. As the *American Journal of Physics* notes, "putting guiding questions in all write-ups… [to] require students to focus on the same elements of the experimental design and communication."[14] These are designed to encourage immediate student comprehension of the lab and also provide suggestions of what information should be detailed in the lab report. As the Anne Cox and William Junkin's study shows, these questions enhance student comprehension of the physical concepts presented in the lab.[15] Furthermore, the information sections were elaborated upon and more derivation of equations were shown to enhance comprehension and decrease the possibility of student confusion. Space was provided to record data, particularly constants and values needed for calculations, at the bequest of current TAs. Furthermore, more space was provided for calculations to be performed in lab. All these changes are designed to enhance comprehension of the material presented.

[12] See Notes about the Lab Report, Appendix A.
[13] See Microsoft Excel How-To, Appendix A.
[14] Etkina, et.al., 980.
[15] Cox and Junkin, 39-41.

- **Lab 3: Motion with Constant Acceleration**

This completely original lab is this project's greatest leap from the status quo.[16] Going in to this research project, a goal was to decrease the number of labs using the air table; although a good tool in theory, it is a tedious, difficult to work with piece of equipment. The air table is inadequate to demonstrate how universal constant acceleration is. The air table makes it appear that constant acceleration can only happen in certain restrained circumstances. The average beginning physics student cannot realize the power and importance, if not omnipotence, of constant acceleration. The new lab will focus much more on hands-on education, so that by increasing student enthusiasm and attention in the lab will increase retention of the material.

Students will stand in front of a black screen that has been demarcated using a grid and toss a ball in a parabolic arch back and forth to each other. Using a high-speed digital camera coupled with a strobe light, a third person will take pictures of the trajectory of the ball. In this photograph, the ball will appear each time the strobe light flashes, forming a parabola-shaped trajectory. Students will then download these images to a computer, and use a computer program to measure the height and position of the ball at various points in its trajectory. Using this data, students use this computer program, complete with the basic kinematics equations, to determine the initial velocity of the ball and the angle at which it was released. An outline of this program, which we have named Kinematics Manipulation, has been designed; these designs and a sample output are displayed in Appendix A.[17]

What is spectacular about this redesigned lab is that it makes visual a concept so fundamental, and yet so hard to grasp, in physics: that the path of a ball tossed in the air is a parabola. As the Lab 3 Program Requirements in the Appendix A show, the camera

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[16] See Lab 3: Motion with Constant Acceleration, Appendix A.
[17] See Lab 3 Program Requirements and Sample Run Through, Appendix A.

perfectly captures this arc of the ball. Even students (and a certain professor) who have studied physics for years were shocked and excited about how perfect of an arc the object's trajectory was. Having first-year physics students study and analyze this data would cement this knowledge and allow them to further understand and appreciate the nuances of the subject. Moreover, the new and original format of this lab would capture student attention and encourage them to continue their studies in physics.

- **Lab 4: Vectors and Forces**

The original lab format relied far too heavily on the force table to demonstrate the two-dimensional nature of forces. Although the force table itself is an ingenious facet for suggesting the relationship between forces, the current lab did not allow for the fact that students did not have to make any calculations or intuitions in balancing the table.[18] They could simply guess-and-check by moving the strings holding weights around the table until it achieved equilibrium. Although we recognize that this could take a long while without a good deal of luck, we also know that many students will prefer this tedious way to having to perform any sort of calculations on their own. To counteract that tendency, we chose to restrict the students' options. In both trials of the lab, either all the positions of the strings or all the masses are fixed or strictly limited by rules. For example, when the masses are restricted, they must follow

$$m_A = m_B = 2m_C \tag{1}$$

One of the set of variables that is not completely restricted will be the value the student solves for to balance the force table. The catch in all of this is that the student is not allowed to touch the force table until they complete the calculations in the space provided in the manual. The

[18] See Lab 4: Vectors and Forces, Appendix A.

ultimate hope is that the TA will witness the first, and only, time the final mass and/or string is put into place. Points will not necessarily have to be taken off if mistakes are made, that is entirely at the discretion of the TA, but we want to quash the guess-and-check method of experimentation currently in practice.

Furthermore, an additional section in this lab tests what students learned in the lab. By making them measure the distance between two points in Small Hall (values which will be entirely at the discretion of the TA) with only a string and a protractor, students will be challenged both creatively and intellectually. They will not have the opportunity to consult textbooks, but rather will have to apply their knowledge of vectors immediately, in a hands-on and unique way that will enhance their overall knowledge of this incredibly important and pertinent idea. This new section replaces what was in the original lab a section devoted to explaining mathematical calculations of vectors. We felt that students in Physics 101, which is a calculus-based physics course, should have had enough experience working with and manipulating vectors that any time spent on this subject in lab would be wasted and ultimately ineffective.

- **Lab 7: Conservation of Linear Momentum**

From previous experience and talking with students, the most significant problem with the original lab format was that the lab was simply too tedious and complicated. Although we agreed that the lab set-up is the best available presently, minor changes to the procedure and hints on how to achieve adequate results on the trial were added in our reworking of it.[19] Furthermore, we sought to improve the effectiveness of the educational component of the lab by

[19] See Lab 7: Conservation of Linear Momentum, Appendix A.

altering the organization and language of the informational sections. The informational sections were separated and interspersed throughout the lab so that students would read the background material immediately before performing that part of the experiment and could easily reference it as needed. Furthermore, these rewritten informational sections were more concise and easy to follow so students could understand them step-by-step. The additional conceptual questions forced students to stay on track of what they should be learning while encouraging them to reach their own conclusions. The included data sections gave students space to record their data and perform calculations, thereby ensuring that they would not forget to complete part of the necessary data collection or calculations. This section also allowed them to check their work while in the lab, and helped the TAs in the grading process.

Once we had our new Lab 7, we set about testing our new style of lab formatting on students. It was important to test this particular lab because of its reputation of being unpopular among the students and generally ineffective. The best way to test our new ideas and verify that they were in fact more educational and effective in the lab was to test them on an original lab we recognized already had faults. We ran three tests during lab sessions in the shortened week after Fall Break, when students did not have their normal labs. The students completed our lab before they performed the original one in their manual, so as to ensure that they were unbiased when they tested our model. After each trial, some alterations were made on the labs. After the first, the conceptual questions were numbered and bolded so students would know they were supposed to answer them in their lab books and not simply ponder them. After the second trial, we realized that the students had not covered momentum yet in class, and so many of them did not yet understand

$$p = mv \tag{2}$$

We added Equation (2) to the informational sections and a bit more background information on the concept of momentum to ensure that students, no matter how much material they had covered in lecture, would be able to follow the lab. No changes were made to the lab after the third trial, because there were no student outcries for assistance.

The following week, after the students had completed the lab as designed in the current manual, I visited the 101 lecture and asked those present to fill out a survey on what they thought of that lab. This survey was very similar to that which students completed after testing the new labs, except that it also asked them information about the amount of time they spent working on the lab report. This group would serve as our control group to determine the effectiveness of our new style of lab.

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

Although conservation of energy is an incredibly important, and indeed fundamental, topic in physics, the original lab manual did not allow for maximum retention of information. First, it did not introduce translational motion at all and focused solely on rotational motion. Excluding translational motion from observation and study in lab denies the student the opportunity to compare the two forms of motion and understand that translational is explicitly a part of rotational. The lab also relied on complex and repeated manipulations of equations to ultimately determine the rate of acceleration of a ball rolling down an inclined track.

$$a = \frac{g \sin \theta}{1 + \frac{I}{Mr^2}} \tag{3}$$

This obscure value is shown in Equation (3), where $M$ is the mass of the disk and $r$ is the radius of the disk's axle. Students were expected to use the motion detector and Data Studio to determine the acceleration of the disk and then compare the experimental and theoretical values. The third problem with the original lab format was that it provided directions for Science Workshop, the previous computer program, rather than the Data Studio program used today.

What was most problematic about this lab, however, was that it did not allow students to understand conservation of energy. By relying on the obscure Equation (3), with little guidance as to how the writers of the manual determined such an equation, the students are force-fed the material at the expense of their own digestion and comprehension of it. Introductory labs should be designed to perk interest in the material, present the information in a comprehensive and easy-to-follow manner, and allow the students to develop intuition about fundamental physical concepts. Many introductory physics classes across the country replicate, or at the very least discuss, Galileo's simultaneous dropping of the feather and ball to demonstrate that gravity is a universal constant; after seeing this performed, students recognize it and add this kernel of wisdom to their physical intuition that will become quite necessary as they move further through the field.

The new conservation of energy lab demonstrates both translational and rotational motion in a manner that will not drastically increase the time spent in lab.[20] Both forms of motion are thoroughly described and explained, and the calculations are listed quite explicitly so that students can follow along rather than just jump to the final answer. Furthermore, the relationship between rotational and translational motion is repeated several times throughout the introductory sections so that students can understand the exact circumstances necessary for the two to be linked the way they are in this lab. The set-up of the lab is the same, albeit with the addition of a block of some sort that will first slide down the track. After many trials with erasers, boxes of chalk, and textbooks, we found that scientific calculators worked adequately, but that another

[20] See Lab 8: Conservation of Energy (Disk and Block on Track), Appendix A.

smoother and more uniform piece of equipment would be the best object to use. The most optimal, in our opinion, would be a stainless steel or heavy plastic rectangular box or object of some sort with a rather substantial mass. An unintended consequence, however, of using a block as well as a disk on the track, is that the incline of the track for the block must be substantially higher. we found this was best maintained when the wooden blocks available on Room 107 were placed under the track.

This new format also requires that students pay greater attention to detail, as the angle of the track, length used in the trial, and mass of the moving object may all vary between the two parts of the lab. Furthermore, the explicit Data Studio instructions allow the students to rely on themselves and not the teaching assistants' help to perform the calculations and create the graphs, thereby increasing their self-reliance while decreasing the pressure on TAs. Moreover, the conceptual questions asked in the lab report, as noted before, force students to consider and comprehend physical concepts while they perform the lab. Lastly, the shift in what is measured from acceleration to velocity allows students to work with a value that is more familiar and relatable to them, as well as one that is used more frequently in energy conservation situations. In general, this new format takes a similar idea to what was used before and expands what is being demonstrated and taught, changes the manner in which it is demonstrated, asks students to study a different value, and makes general improvements in the structure and format of the lab.

## Conclusions

➢ **Lab 7**

We found that students responded favorably to our new lab format, even given the fact that the material was unfamiliar to many before they performed the lab. Although we did hear a fair share of complaints about the length of the lab, many were quite pleased that they would not have to write a lab report. The quantitative survey answers for the redesigned lab are listed in Table 1; students were asked to answer the questions on a scale of 1 through 5, with 1 denoting "very good" and 5 denoting "very bad." Students were also given the opportunity to provide qualitative feedback—what they liked and did not like about the lab, what seemed especially confusing, and what about the new lab was most useful or enjoyable to them.

| Q 1 | | Q 2 | | Q 3 | | Q 4 | | Q 5 | |
|---|---|---|---|---|---|---|---|---|---|
| Score | Number Respon-dents | Score | Number Respon-dents | Score | Number Respon-dents | Score | Number Respon-dents | Score | Number Respon-dents |
| 1 | 13 | 1 | 6 | 1 | 9 | 1 | 13 | 1 | 14 |
| 2 | 15 | 2 | 20 | 2 | 18 | 2 | 11 | 2 | 11 |
| 3 | 6 | 3 | 9 | 3 | 7 | 3 | 11 | 3 | 5 |
| 4 | 4 | 4 | 2 | 4 | 5 | 4 | 3 | 4 | 8 |
| 5 | 2 | 5 | 3 | 5 | 1 | 5 | 2 | 5 | 2 |

Table 1: Collected Data from Surveys for New Lab 7

In total, forty students tested our redesigned lab. The results, for the most part, were quite favorable. On average, 26 students (or 65% of the test group) rated this lab in the top two categories, either "somewhat good" or "very good." Furthermore, the percentage of students who felt that this redesigned lab was "very bad" was a mere 5%.

Figure 2 below graphically portrays student answers to the first question, which asked students to compare the layout of this lab to other labs they have completed in the past. The few dissenters expressed dissatisfaction with the fact that all the informational sections were interspersed with the lab itself; however, most students responded positively because it allowed for easier access to and better comprehension of the material. The statistics prove this: the mean response to Question 1 was a 2.2 with a standard deviation of 1.3. Clearly, most students were genuinely pleased with the new layout of this lab.

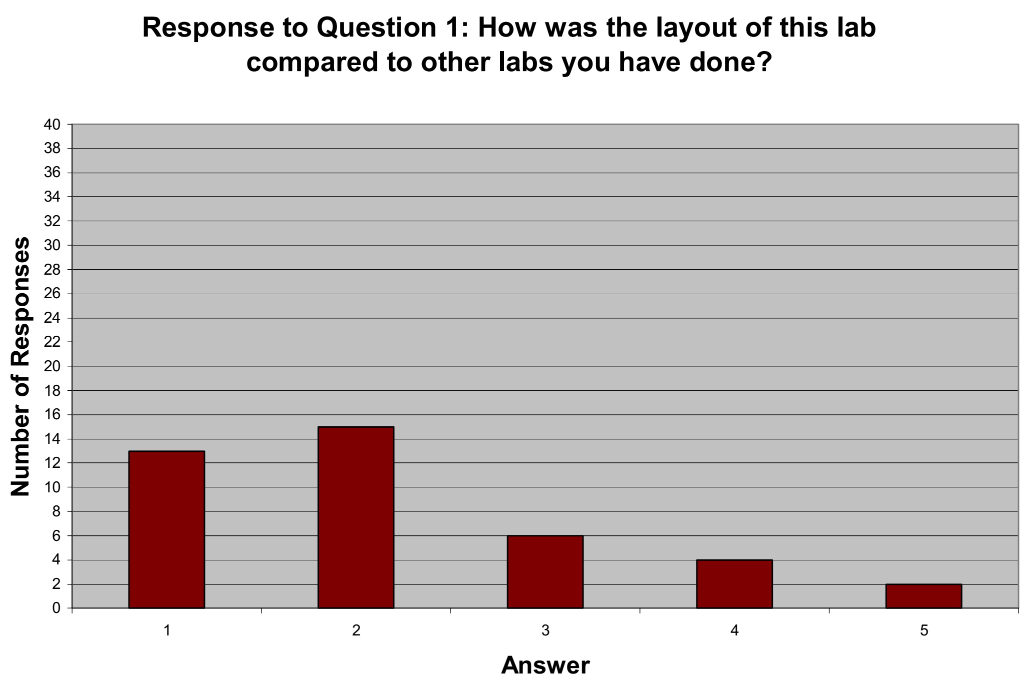


Figure 2: Cumulative Responses to Question 1 for New Lab

Similarly, Figure 3 below demonstrates that the procedures in the refined lab were clear and easy to understand. Those students who ranked us poorly were tested in the first trial, when many of the kinks were still being worked out of the format. After making improvements in language and sentence syntax, the students in the latter two trials reported scores of no worse than three. As Figure 3 suggests, a vast majority of the students (35 out of 40 polled) felt the procedures were clear. Understanding the procedures allowed students to better comprehend not only what they were supposed to do in the experiments but the presented material as well. The mean score was a 2.4, with a standard deviation of 1.0.

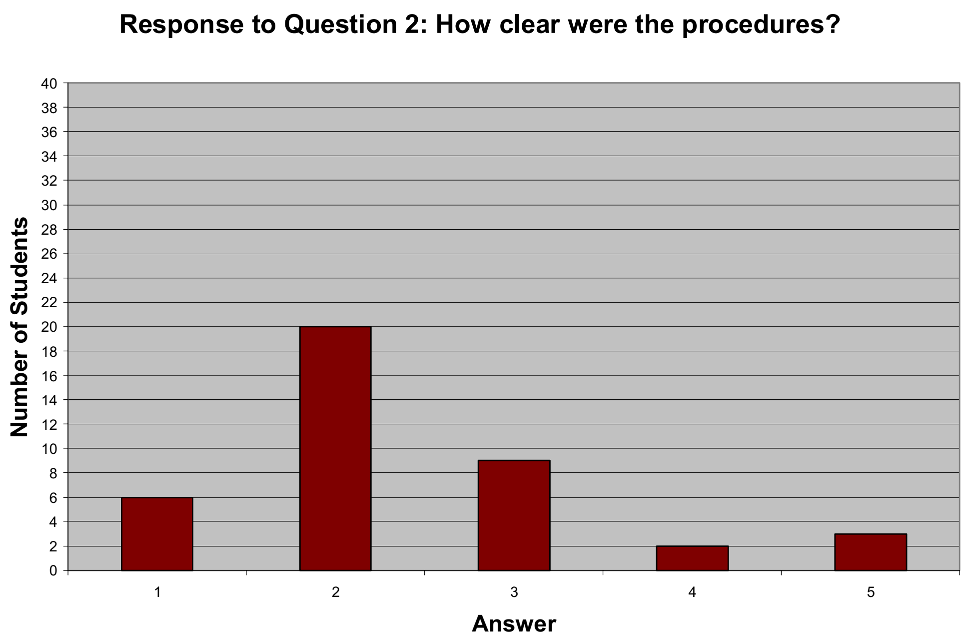


Figure 3: Cumulative Response to Question 2 for New Lab

Furthermore, Figure 4 below suggests that students were fairly pleased with the order in which the information was presented. The mean response was 2.4 with a standard deviation of 1.0. Very few students were openly dissatisfied with the order of information presented in the lab. Many expressed satisfaction with the fact that the organization of the lab now enabled them to better understand the material being presented; indeed, just under half of all students surveyed ranked the helpfulness of the order of information as "somewhat good." They were able to understand the concepts while actually in the lab, rather than having to wait until they struggled through a lab report in the hope of actually learning something. Furthermore, they did not have to keep flipping back and forth in the lab manual looking for the necessary information; the material was provided directly before the experiment, allowing for easy access.

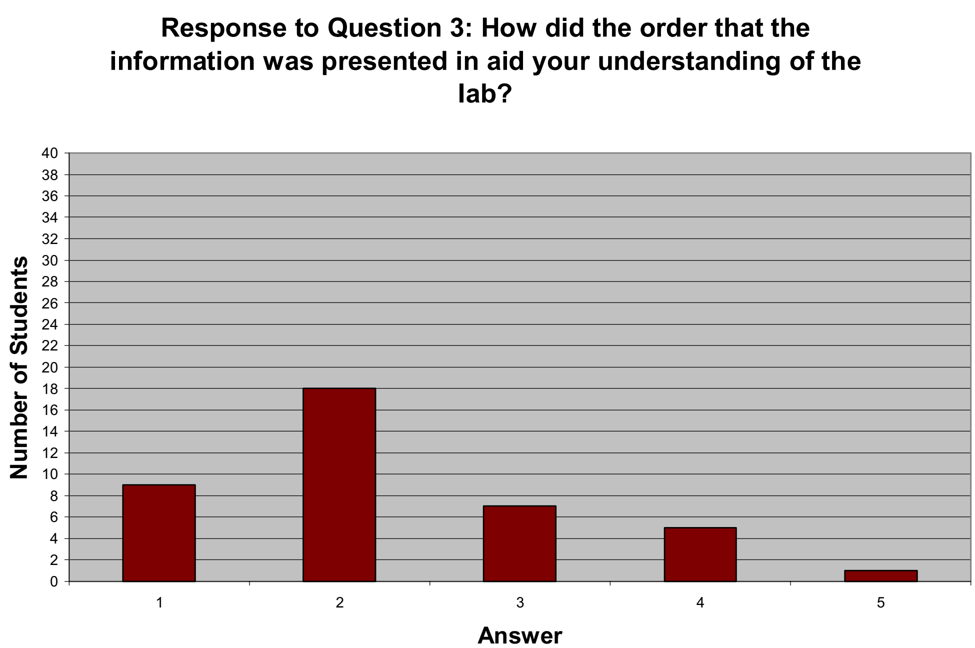


Figure 4: Cumulative Response to Question 3 for New Lab

As Figure 5 shows, the new lab format presented the background information in a clear and concise manner. Clarity in the lab instructions is incredibly important, because if the students cannot learn the material in the lab, then there is no purpose in them completing the lab in the first place. Students responded positively to such a format, because they actually felt like they were learning something in the lab. The mean response was 2.3 with a standard deviation of 1.3. What is interesting in this particular graph, however, is the overall shape of the bars. The first three possible answers all received very similar numbers of responses, while hardly any students ranked the informational sections as "somewhat bad" or "very bad."

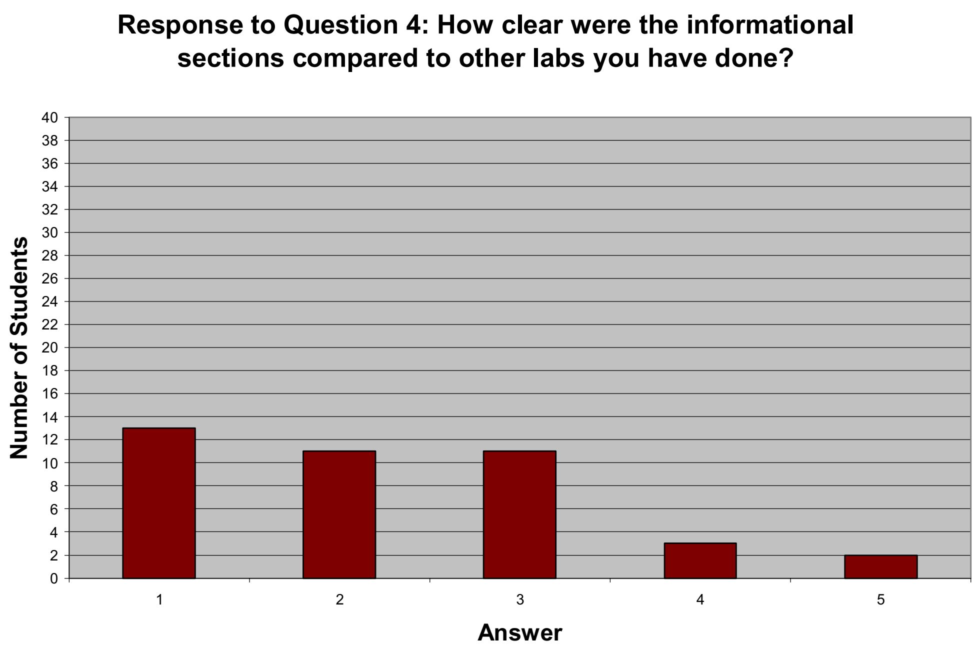


Figure 5: Cumulative Response to Question 4 for New Lab

Figure 6 shows the most widely dispersed range of answers to the question of the effectiveness of the data and analysis sections. A number of students who came to the tests of the new labs, much to our surprise, expressed dismay at the thought of no lab report; they, surprisingly enough, find reports to be helpful, useful, and beneficial. We knew when we started this project that not every student would necessarily be thrilled by the changes we made to the labs. However, a great many students (30 in total, or 75%) expressed positive sentiments about our newly designed data and analysis sections, where the data is recorded and calculations made there in the lab rather than outside after completion of the lab. The mean response was 2.3, with a standard deviation of 1.3. Even with the naysayers, a great many students were pleased with the changes in the lab manual, particularly the absence of a lab report for this lab.

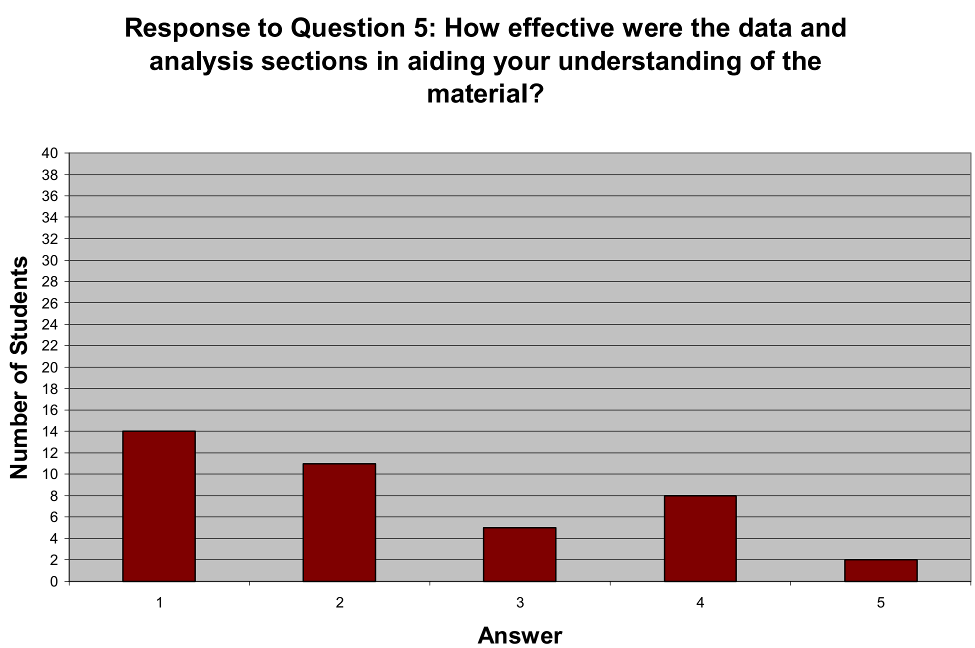


Figure 6: Cumulative Response for Question 5 for New Lab

Students were also given the opportunity to provide qualitative feedback—what they liked and did not like about the lab, what seemed especially confusing, and what about the new lab was most useful or enjoyable to them. These comments are listed in Table 2 on the succeeding page.

These qualitative concerns were taken into careful consideration during the testing procedure. As a number of students complained about the lab format or expressed confusion over whether or not to answer the prompted questions, Melissa and I edited and modified the lab to rectify these problems. The information sections were lengthened as a result, and clarifications in the procedural part of the manual were made as well. At the same time, however, complaints about the length of the lab or the tediousness of making measurements could not be remedied. That is the nature of scientific research and, try as we might, it is not a characteristic that we can easily change. Patience and time are simply mandatory for the 101 labs.

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

Table 2: Qualitative Responses to Survey for New Lab 7

To serve as a basis of comparison, students in the Physics 101 class were asked to fill out a survey about the original Lab 7 the week after they turned in that lab report. We felt these surveys were necessary to give us a better understanding of how successful our new lab format was. In total, 78 students filled out the survey, but not every student, for uncertain reasons, answered every question. The total number of respondents for each question ranged from 74 to 78 students. These results are displayed in Table 3.

| Q 1 | | Q 2 | | Q 3 | | Q 4 | | Q 5 | |
|---|---|---|---|---|---|---|---|---|---|
| Score | Number Respon-dents | Score | Number Respon-dents | Score | Number Respon-dents | Score | Number Respon-dents | Score | Number Respon-dents |
| 1 | 8 | 1 | 18 | 1 | 9 | 1 | 8 | 1 | 12 |
| 2 | 28 | 2 | 35 | 2 | 21 | 2 | 21 | 2 | 23 |
| 3 | 30 | 3 | 8 | 3 | 33 | 3 | 33 | 3 | 25 |
| 4 | 10 | 4 | 13 | 4 | 8 | 4 | 9 | 4 | 13 |
| 5 | 0 | 5 | 0 | 5 | 7 | 5 | 4 | 5 | 2 |

Table 3: Collected Data from Surveys for Original Lab 7

Overall, the original lab was favored much less than the redesigned one. The mean number of students who rated this lab in the top two categories was 37, which was roughly 47% of the polled group. Ten more students ranked this lab more favorably than they had the redesigned one, but the percentage of students who did so was far less than the 65% in our redesigned lab. The mean responses tended to lean much closer to the "neutral" range in the original lab, whereas in the redesigned labs the averages were closer to the "good" range. What initially surprised us was how many students seemed relatively satisfied with the original lab, which we thought was overall ineffective and inferior to the other labs in the manual, not to mention our redesigned one. However, students still preferred the new and improved lab to the one currently used in class.

The results of Question 1 for the original lab are shown in Figure 7. The mean response was 2.6, and the standard deviation was 1.2. More students were displeased with (or at the very least more neutral towards) the original lab format than with the redesigned one. Some students found the measurement process tedious and did not favor the separation of the informational sections from the procedural instructions. Others, however, felt the layout of the lab was good relative to others they have performed. Still, the shape of the graph is a sort of bell-curve, in contrast to the earlier figures for the new lab, which displayed a majority of the responses in the first two categories.

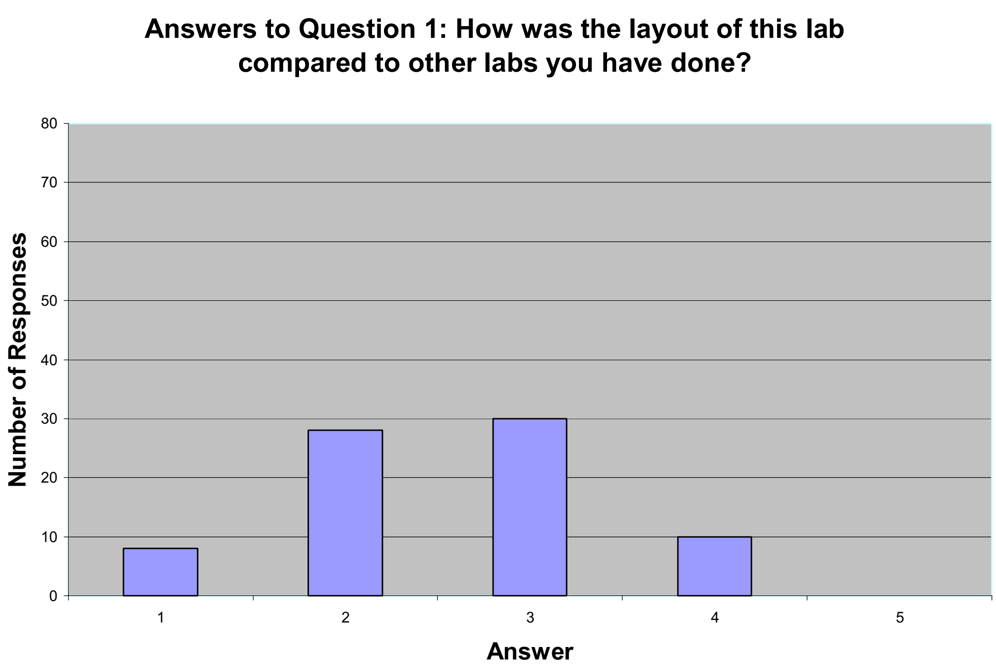



Figure 7: Control Group Response to Question 1 for Original Lab

Surprisingly, a great deal of students felt that the procedures in the original lab were clear, as the results in Figure 8 show. The mean response was 2.2 with a standard deviation of 1.0. What is important to note, however, is how varied the responses were. A good number of students thought the procedures were very clear, while at the same time a good number believed them to be fairly vague. The new lab did not cause this same level of dichotomy in responses, and indeed appeared to have provided overall clear and comprehensible procedures for the majority of students. That, after all, was the point of this research project—to clarify the procedures and goals of the lab so that the average student could perform well in the educational environment.

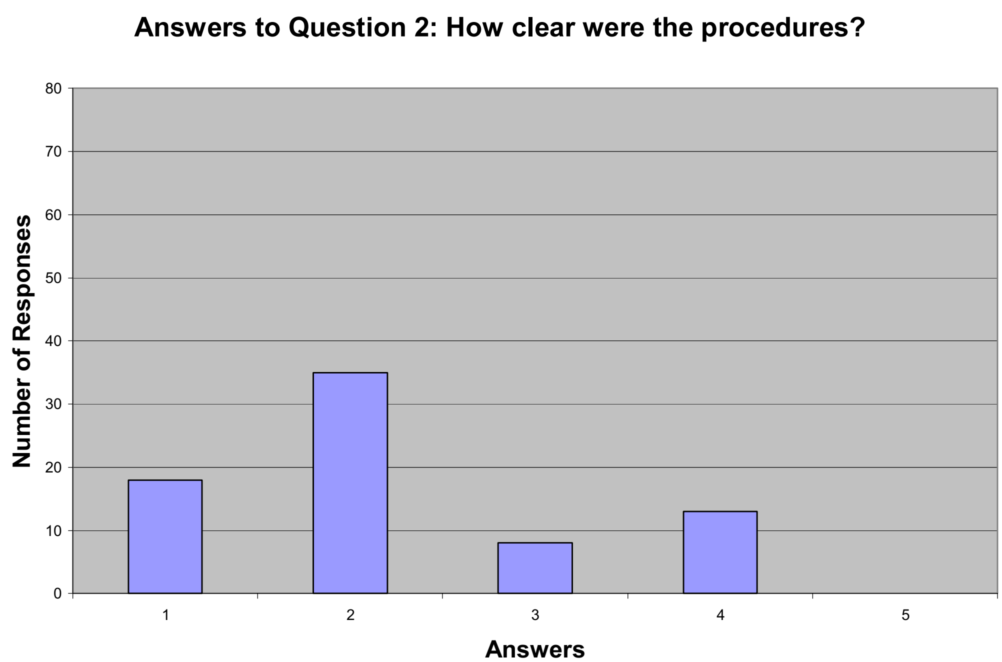



Figure 8: Control Group Response to Question 2 for Original Lab

Figure 9, which graphically depicts the results of Question 3 for the original lab, continues the bell-curve trend alluded to in Figure 7. The mean answer was 2.8 with a standard deviation of 1.0. For the most part, the students were neutral in their feelings about the order of information in the lab—no one thought it spectacular, but no one really hated it either. In general, this lack of enthusiasm in either direction signifies a great underlying problem in the labs. They do not encourage a positive student response or level of enthusiasm. The order of information needs to be presented in a way that ensures students comprehend the lab itself and the material it is supposed to teach them. When almost 60% of students surveyed express that this is not the case, there must be a problem with the lab itself.

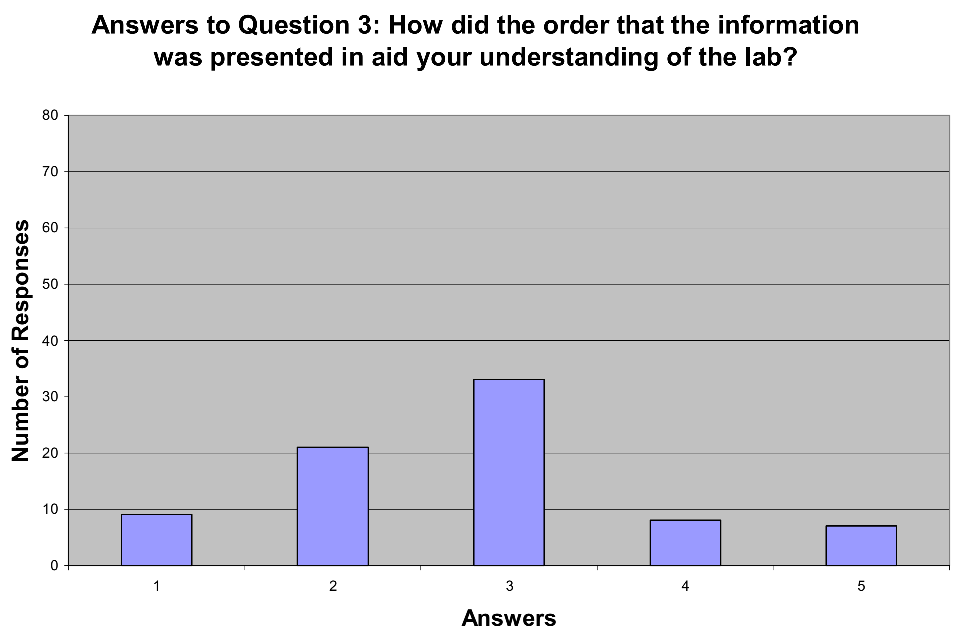



Figure 9: Control Group Response to Question 3 for Original Lab

The graph of results to Question 4, shown in Figure 10, continues the aforementioned bell-curve trend in a much more pronounced manner than any of the previous graphs. The students appeared to be much more neutral to this lab, and the numbers showed this as well. The mean was 2.7 with a standard deviation of 1.0. The students were not particularly impressed with the original lab's information sections, but neither were they disappointed or frustrated either. This implies that the original lab's information sections were on par with the average level of clarity in the lab manual. Regardless of how clear this average level is, the information sections definitely need to be improved so that more students feel more favorable to them, as they did in the redesigned lab. Students should not have to question the informational sections or the material presented therein. They must be able to comprehend what is being presented in order to execute the lab and further their knowledge of the material.

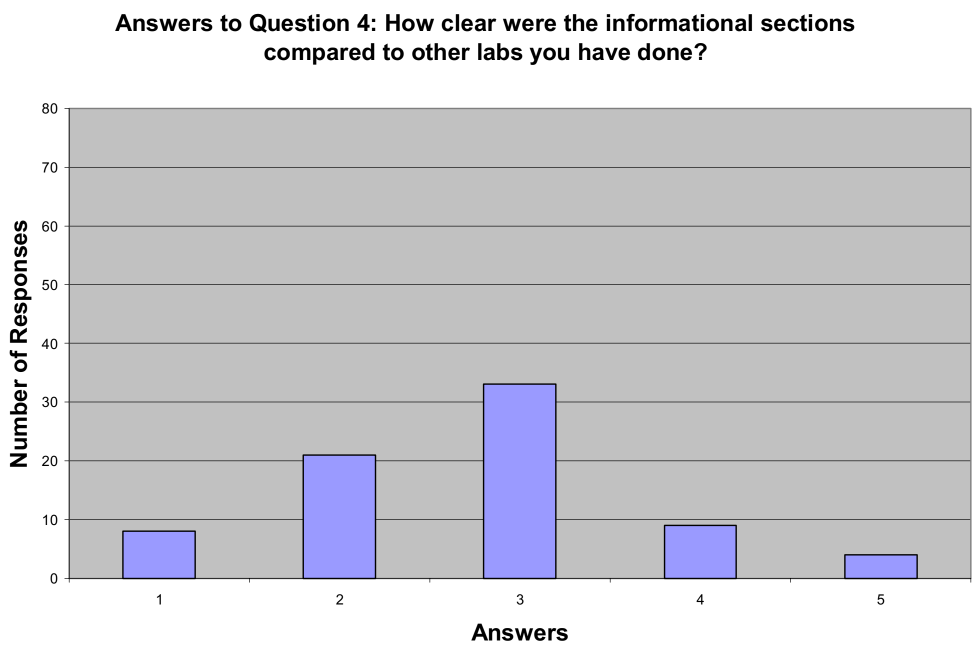



Figure 10: Control Group Response to Question 4 for Original Lab

Figure 11 below graphically depicts the student response to Question 5 for the original lab. As before, this curve has a distinct bell-curve shape, albeit one favoring the positive end of the spectrum. The results to this question were surprising. I did not feel that the original data and analysis sections were effective or helpful in any manner. However, the mean student response was 2.6, with a standard deviation of 1.0. Students evidently believed that these data sections were helpful in comprehending the presented material. Still, students who participated in the test of the redesigned lab favored those new data sections more, providing further implication of the superiority of the new lab format.

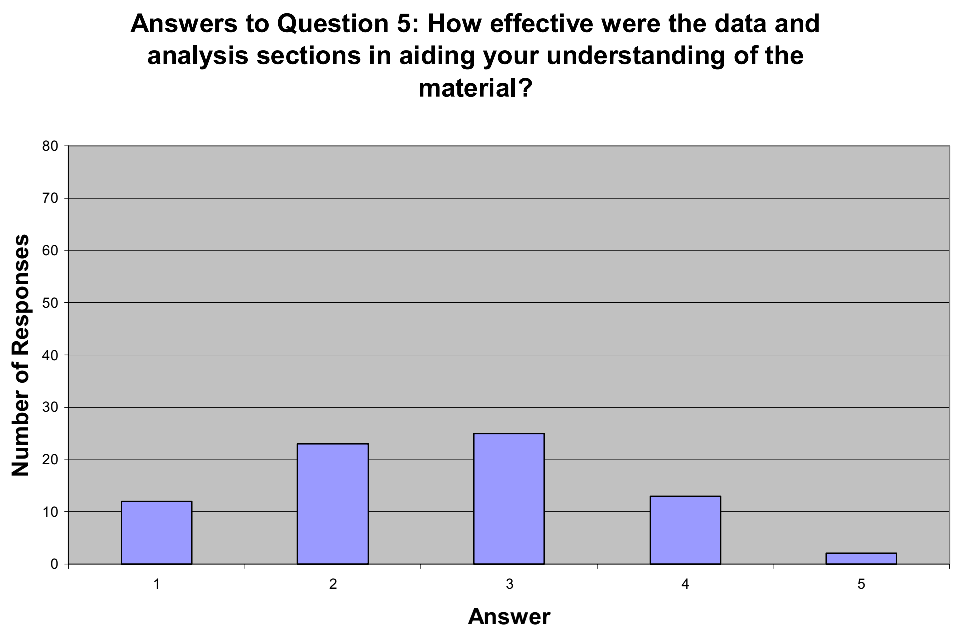



Figure 11: Control Group Response for Question 5 for Original Lab

As in the other survey, students were encouraged to provide qualitative feedback and observations on the original lab. The responses are listed below in Table 4. Many students testified that they felt the measurements on the air table were tedious and overly time-consuming. Students also found that the procedural and informational sections are confusing. If they cannot understand the material or what they are supposed to do, there is no way they will be able to further their physical knowledge. A significant number also admitted that the lab report was not an effective educational tool and that they did not understand its purpose. All of the above demonstrate a massive overall problem with the lab manual—students *must* understand why they are performing the labs and why the material is pertinent to their education in physics. Otherwise, the execution of these labs is futile for the students.

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

Table 4: Qualitative Survey Results from Original Lab 7

In the control group's survey, an additional question, as noted before, asked them to estimate the time they spent working on the lab report. We wanted to see how much time, in and out of lab, they were spending on research or the understanding of it, and we also wanted to know if they thought lab reports were an effective use of their time. The results are displayed in Table 5 below, and the results for time spent on the report are graphically displayed in Figure 12 on the next page.

| Time in lab | | Time on Report | | Effective use of time? | |
|---|---|---|---|---|---|
| Hours | Number Respon-dents | Hours | Number Respon-dents | Answer | Number Respon-dents |
| 1 | 15 | 1 | 3 | Yes | 20 |
| 1.5 | 22 | 2 | 22 | No | 40 |
| 2 | 22 | 3 | 22 | | |
| 3 | 0 | 4 | 9 | | |
| 4 | 0 | 5 | 3 | | |
| 5 | 0 | 6 | 0 | | |
| | | 7 | 0 | | |
| | | 8 | 2 | | |

Table 5: Collected Data about Time Concerns from Original Lab 7

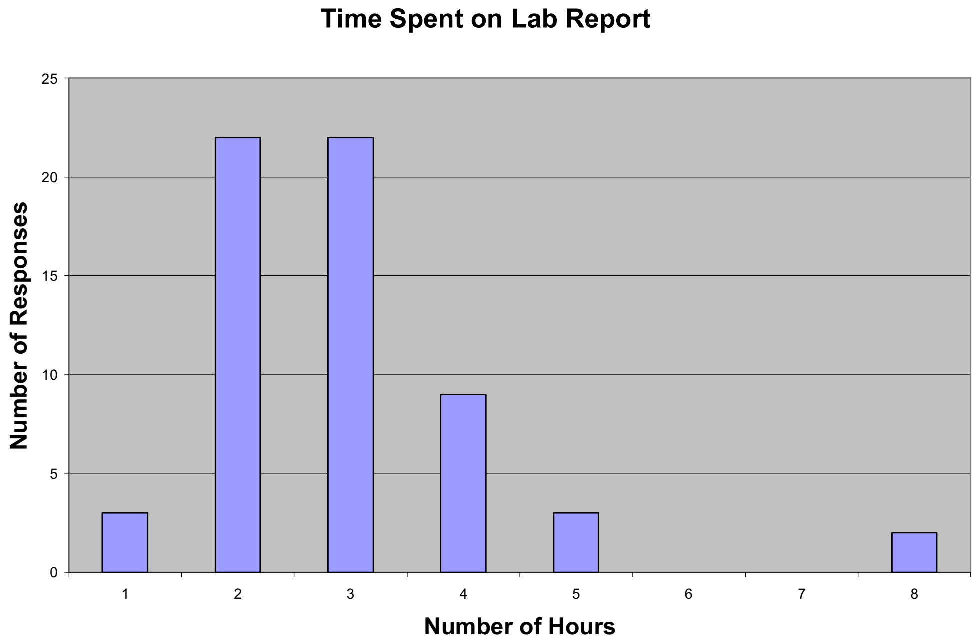



Figure 12: Number of Hours Spent on Lab Report for Original Lab

As Figure 12 above demonstrates, a vast majority (over 70%) of students spent at least an additional two hours working on the lab report; this does not include any time spent in lab performing the experiment itself. The mean amount of time spent was 3.0 hours, with a standard deviation of 1.3. Of the 61 students that responded to the question of effective use of time, 40 responded that they did not feel that it was. Almost two-thirds of the students did not believe the lab reports were effective educational tools, in large part because they consumed so much of their time. This correlates with our research that lab reports, a form of passive learning, are not as effective as the active and hands-on learning that labs themselves stimulate.

What should be noted is the nature of the test group. Because Professors Chaloupka and Armstrong provided a small amount of extra credit to those students who participated in our study, I am afraid we may have received a polarized group of students: those grade-focused with a strong interest in science and physics already versus those who are struggling to get by and desperate for help anywhere they can get it. Although the extreme tendencies of both groups would neutralize the other, I would have liked to test the “average” student as well, since this is the student toward which this project is pointed. Again, this is a hypothesis as to the nature of the group, but it would explain the desire by some students to have a lab report, since those already science-oriented would prefer to continue with what they already know.

- **Lab 8**

As with the redesigned Lab 7, we also tested the refined Lab 8. Because of time constraints and room availability, the lab was only tested once instead of the three trials for Lab 7. Furthermore, this lab was never compared to the original Lab 8 in the manual, in large part because students completed Lab 8 so long ago that any answers would be inaccurate and unfair to use. The survey was the same used in the previous lab tests. Five questions with quantitative answers were posed, and then students were given the opportunity to make qualitative comments and suggestions. The results of this survey are displayed in Table 6.

| Q 1 | | Q 2 | | Q 3 | | Q 4 | | Q 5 | |
|---|---|---|---|---|---|---|---|---|---|
| Score | Number Respon-dents | Score | Number Respon-dents | Score | Number Respon-dents | Score | Number Respon-dents | Score | Number Respon-dents |
| 1 | 2 | 1 | 5 | 1 | 5 | 1 | 6 | 1 | 5 |
| 2 | 7 | 2 | 6 | 2 | 6 | 2 | 5 | 2 | 7 |
| 3 | 5 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 1 |
| 4 | 0 | 4 | 0 | 4 | 1 | 4 | 0 | 4 | 1 |
| 5 | 0 | 5 | 0 | 5 | 0 | 5 | 0 | 5 | 0 |

Table 6: Collected Data from New Lab 8

In total, fourteen students tested the new Lab 8 and completed surveys. Although is an admittedly small group of students, it is still a fairly accurate statement of the effectiveness and overall student sentiment toward this new lab. On average, 11 students, or 77% of the test pool, ranked the lab as either good or very good. This high of a percentage, even with such a small group of test subjects, is a remarkable statement on the effectiveness and educational fortitude of this redesigned lab.

As Figure 13 demonstrates, students responded favorably to the layout of this redesigned lab. The mean response was 2.2, with a standard deviation of 0.5. This low level of variance demonstrates that students were remarkably similar in their positive attitudes toward the organizational layout of the lab. Students appreciated the Data Studio instructions woven into the lab itself, which prevented them from having to flip through lab manuals hunting for directions on how to use the computer program. They commented that this lab was more student-friendly than others they had worked with and appreciated that the layout did not require them to make large leaps in assumptions or proofs to understand the material being presented.

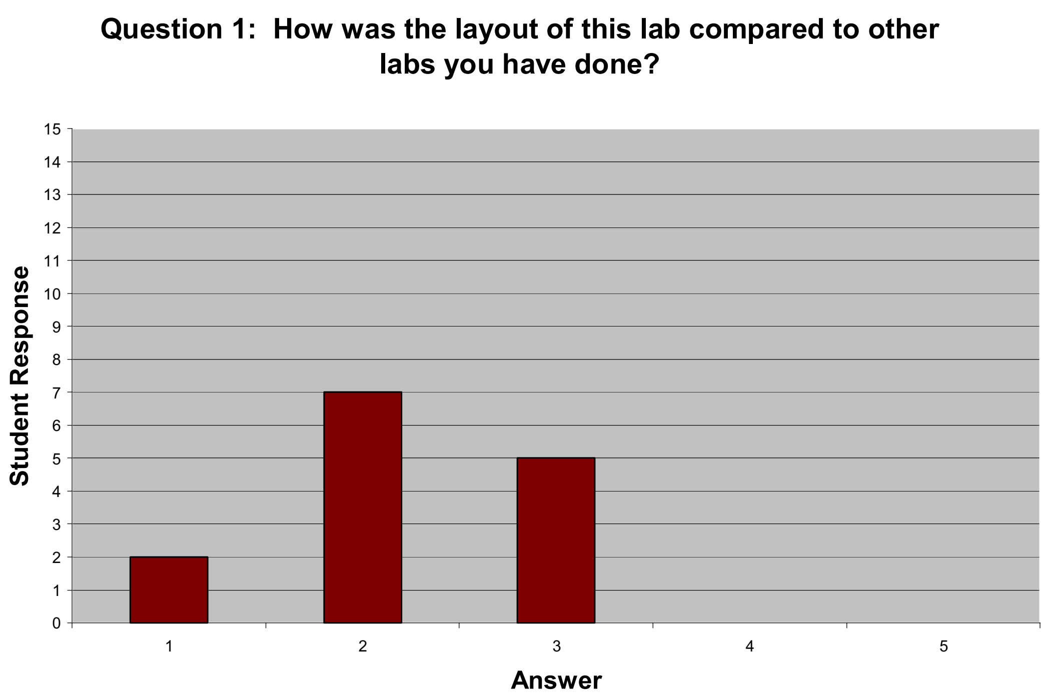



Figure 13: Cumulative Response to Question 1 for New Lab 8

Furthermore, students also felt that the procedures for this redesigned lab were quite clear. They understood exactly what was expected of them, and this allowed them to better comprehend the material being presented in the lab. No student rated this lab below "neutral" in terms of its clarity. Figure 14 below gives the complete graphical depiction of student responses. The mean student response was a remarkably low 1.9 with a standard deviation of 0.7. Again, students greatly appreciated the inclusion of Data Studio instructions into the lab itself. It allowed them to focus on performing the lab rather than wonder and worry about how to use the computer program.

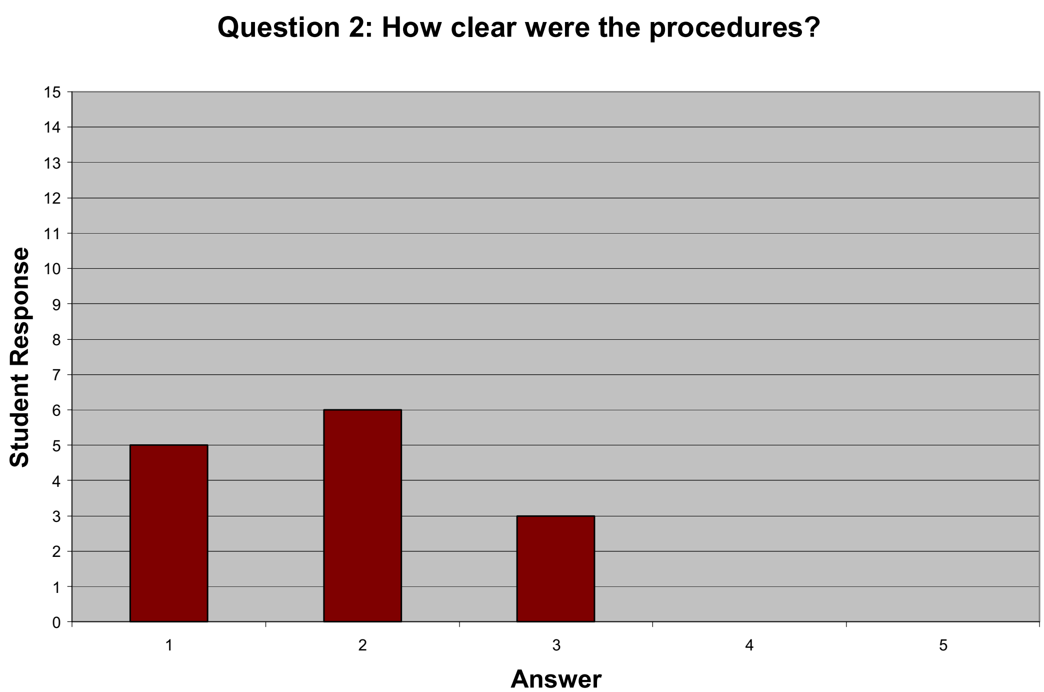



Figure 14: Cumulative Response to Question 2 for New Lab 8

Students also responded positively to the order of information in the lab. As Figure 15 shows, 11 of the 14 students, or just under 80% of the group, felt that the order of information was presented in a "somewhat good" or "very good" manner. Indeed, the average student response was a low 1.9 with a standard deviation of 0.9. A vast majority of students liked that the informational sections about rotational and translational motion were separated because it allowed them to focus on one at a time and not get confused along the way. By first explaining kinetic and potential energy, and then explicating the difference between what happens in translational motion and later rotational motion, students were better able to comprehend what was happening as objects moved down the track.

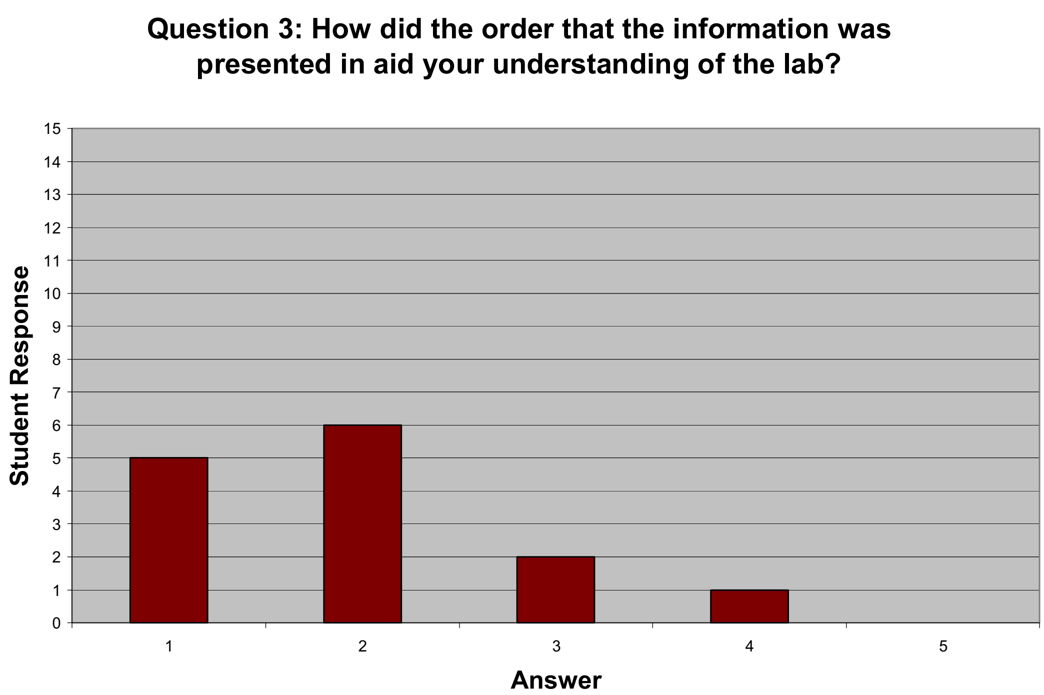



Figure 15: Cumulative Response to Question 3 for New Lab 8

The student response was again quite positive in the area of clarity of informational sections. Like had happened in Questions 1 and 2, virtually no one gave this question a lower ranking than "neutral." The mean response, as Figure 16 demonstrates, was a low 1.8 with a standard deviation of 0.8. Indeed, the bell-curve shaped graphs like those in the results of the original Lab 7 tests are not existent in these evaluations. Eleven of the 14 surveyed students, or just under 80% of the students surveyed, felt that the level of clarity was good or very good. This result, I believe, is a testament of the clear and explicit development of equations; even relatively simple rearrangements were produced on paper to ensure that students followed every step of the process. Such well-developed and thorough informational sections allowed students to better absorb the material before they performed the lab so that they could better understand the results after they produced them.

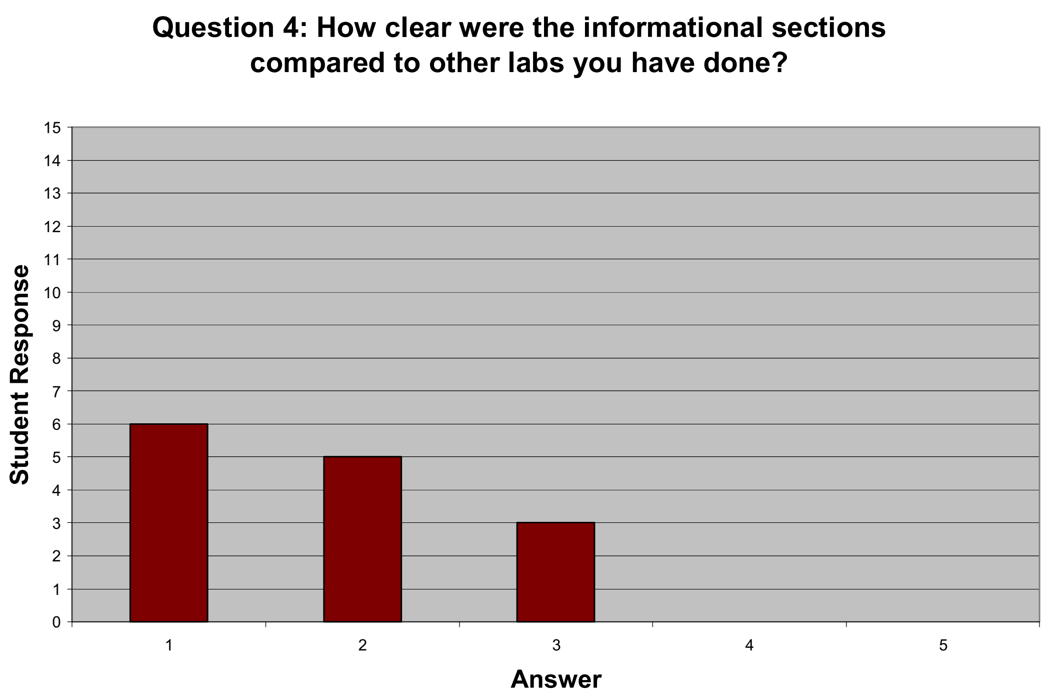



Figure 16: Cumulative Response to Question 4 for New Lab 8

Students, as Figure 17 shows, greatly appreciated the data and analysis sections of the new Lab 8. The mean student response was 1.9 with a standard deviation of 0.8. Over 85% of the students surveyed, or 12 of the 14 individuals, considered the data and analysis sections to be "somewhat good" or "very good." Unlike in the redesigned Lab 7, students were still required to compose a lab report. However, the spaces provided for the recording of data, including constant measurements, and performing calculations allowed students to perform much of the analysis in the lab itself. Therefore, any questions that may develop later could be answered by the TA immediately rather than struggled over while the report was being written. Furthermore, these spaces ensured that students would not overlook making a measurement or mistakenly record it elsewhere. Having all data in a centralized location decreased the chance of external complications affecting analysis.

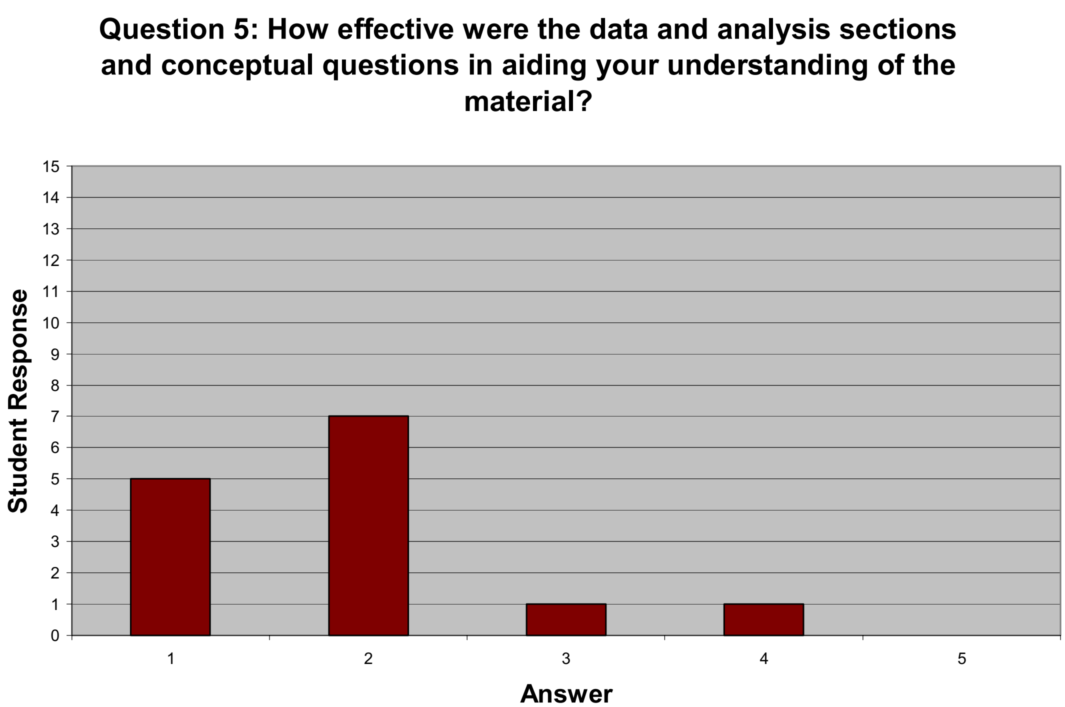



Figure 17: Cumulative Response to Question 5 for New Lab 8

As in the previous lab tests, students were asked to provide qualitative feedback as well. These problems, concerns, suggestions, and feedback are listed in Table 7 below.

| 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 | |

Table 7: Qualitative Survey Results from Lab 8

The absolute greatest problem with the new lab was finding a block to use for the translational motion section of the experiment. A calculator at first appeared to be a decent substitute for a uniform block, but many students had trouble getting the calculator to move appropriately. Indeed, it was almost a universal complaint for the lab. In the future, I believe a smooth stainless steel or heavy plastic block would work best. They can be bought or made cheaply and in bulk, so that everyone uses something of similar mass, size, and coefficient of friction. Furthermore, the greater the mass and the less friction an object produces, the easier it would be for students to make the object move. With the calculator, students needed to lift the track to an incredibly high angle that made the acquisition of measurements difficult. Furthermore, if an object could be found that would move at an angle similar to that which makes the disk roll, students could better understand the difference between translational and rotational motion.

Overall, however, students reacted positively to the changes made in the new Lab 8. They were pleased with how little time it took to perform the lab, particularly because the Data

Studio instructions were explicitly detailed in the lab itself. They thought this new lab was more effective at teaching the material and that Data Studio now helped analyze the material for comprehension rather than serve as a hindrance in its performance, as it had done so previously. Ultimately, this new lab was a more effective educational tool than its original counterpart.

**Final Thoughts**

Overall, I believe this senior research project accomplished what Melissa and I set out to do. We designed four new labs that will improve the effectiveness of the education of the Physics 101 Labs. Moreover, I believe we have set a precedent for improvement of the lab program in general. I am not so naïve to think that every suggestion or revision that we have made will be implemented in the future. What I would like to believe, however, is that we have shown through the course of this project that reports are not absolutely essential to the learning process, that students should be encouraged to learn and understand the material in the laboratory rather than in their dorm rooms, and that advanced technology can improve the quality of lab instruction.

# 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 and invaluable 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 will have performed in five years. What we hope you take out of this class and lecture, rather, is a better understanding of the scientific process and scientific inquiry. 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 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.

## 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

### 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:

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

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

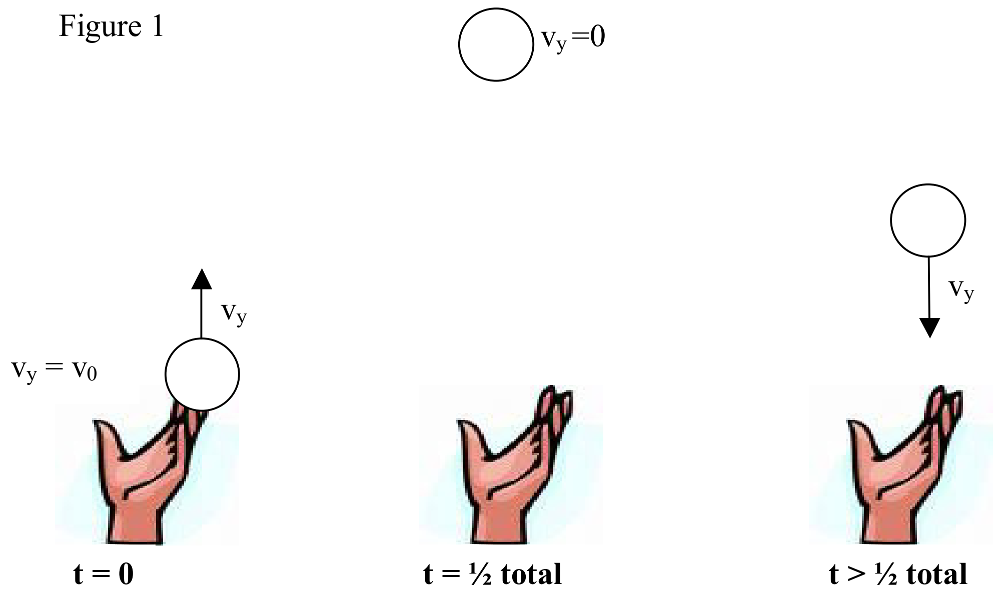
$$y = y_0 + v_{y_0} t + \frac{1}{2} a_y t^2 \tag{3}$$

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.

**Q 1. What is the acceleration of the ball when it reaches its highest point?**

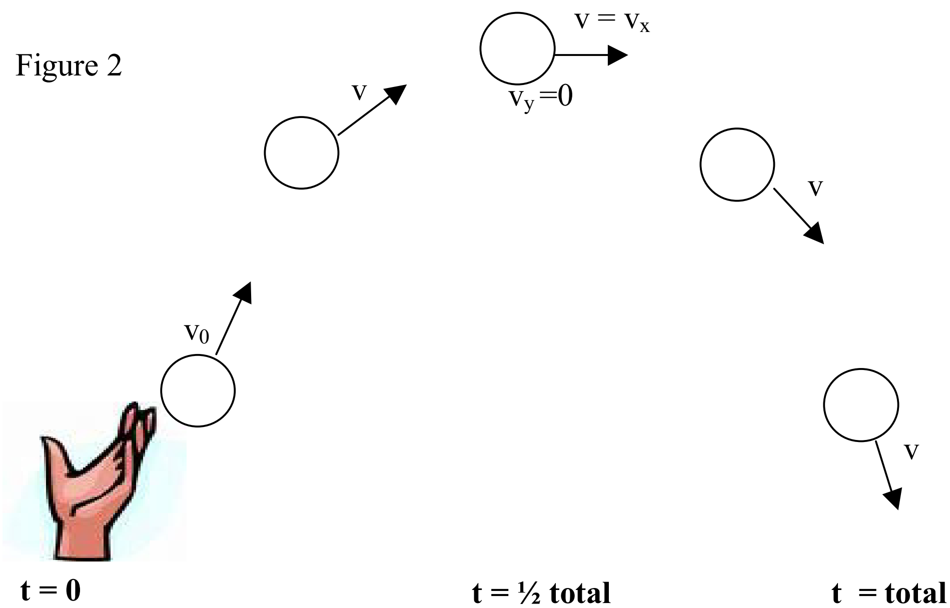
**Q 2. What is it's velocity at the highest point?**

**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 $v_y$.

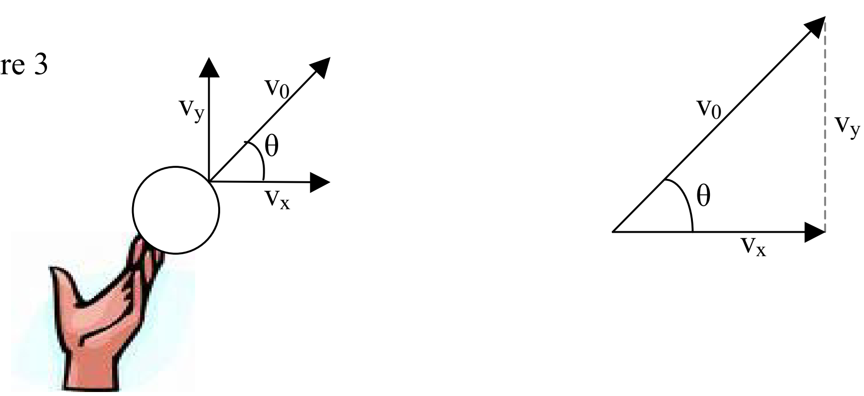
**Q 3. How does the acceleration in the x-direction affect the path of the ball?**

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:

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

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

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:

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

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

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

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.

**Q 4. 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, $a_x = 0$.

**Q 5. What is the ball's velocity in the x direction if it has an initial x velocity of .25m/s?**

**Q 6. 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 $v_{y_0}$.
    - 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

**Q 7. How does the velocity and angle calculated compare with your expectation of the values based on looking at the photo?**

**Q 8. Explain any errors that may have occurred.**

## Lab 3 Program Requirements and Sample Run-Through

**Purpose:** 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.

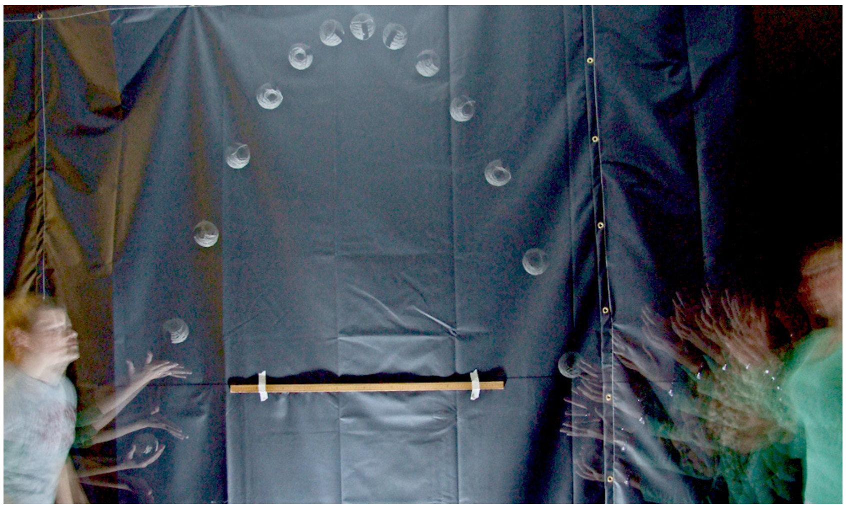


Figure 1: Photo of Ball Trajectory

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.

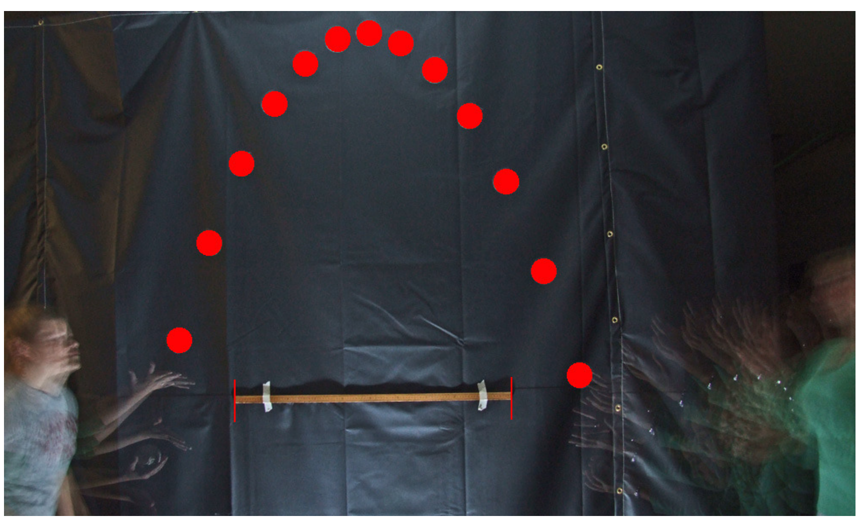


Figure 2: Photo of Ball Trajectory with Points

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.

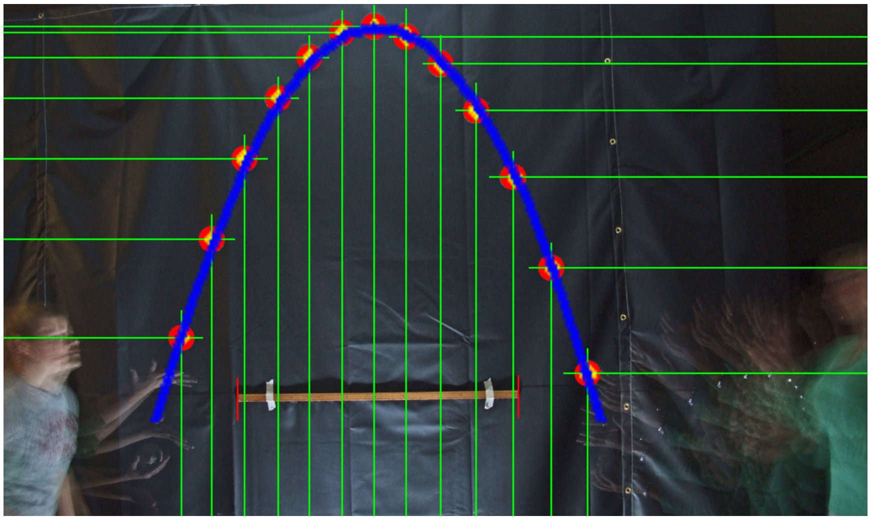


Figure 3: Photo of Ball Trajectory with Points and Gridlines

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

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

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

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

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 below:

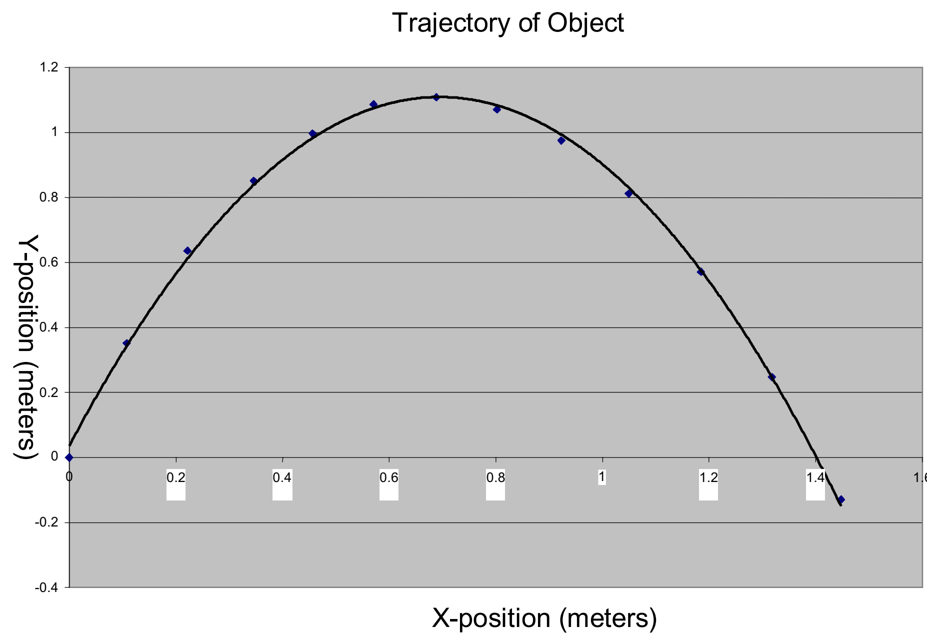



Figure 4: Line of Best Fit for Ball Trajectory

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:

$${v_y}^2 = v_{y_0} + 2a_0(y - y_0) \tag{5}$$

The computer program will rearrange this equation to produce:

$$v_y = \sqrt{{v_0}^2 - 2a_y(y - y_0)} \tag{6}$$

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 Equation 1 from above. The computer program will rearrange said equation to solve for t, so that it becomes:

$$t = \frac{(v_y - v_{y_0})}{a_y} \tag{7}$$

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:

$$x = x_0 + v_{x_0} t + \frac{1}{2} a_x t^2 \tag{8}$$

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:

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

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:

$$|v| = \sqrt{{v_{x_0}}^2 + {v_{y_o}}^2} \tag{10}$$

$$\tan\theta = \frac{v_{y_0}}{v_{x_0}} \tag{11}$$

Equation (10) gives the magnitude of the initial velocity as 4.85729m/s and, Equation (11) gives the initial angle of the throw to be 73.67868°.

# 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, $\theta$.

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.

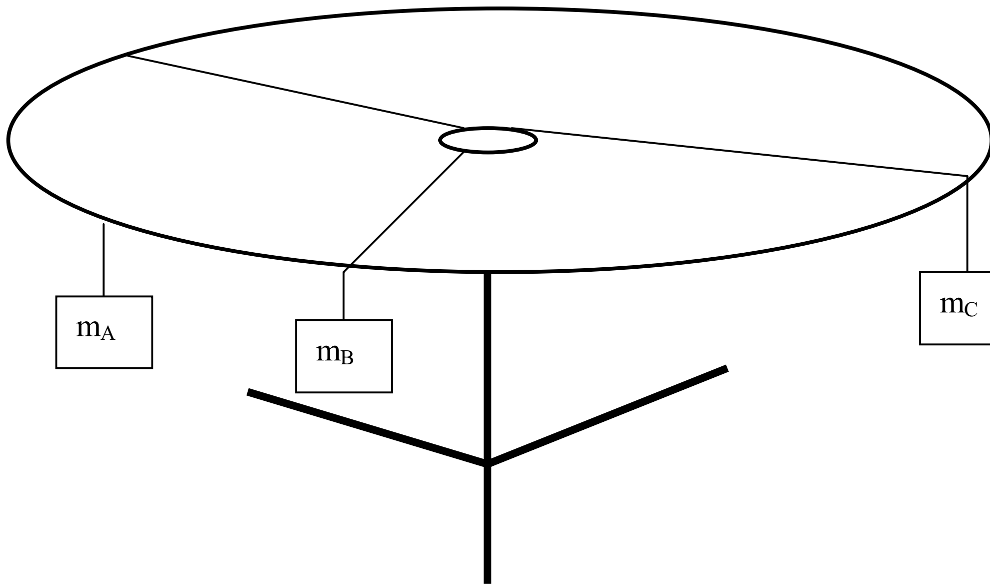



Figure 1: The Force Table

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

$$\left|\vec{F}\right| = m_i g, \tag{1}$$

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

$$\vec{F}^{tot} = \sum \vec{F}_i \tag{2}$$

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:

$$\vec{F}_{tot} = \vec{F}_A + \vec{F}_B + \vec{F}_C = 0 \tag{3}$$

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 $\theta_A$ 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.

## 4.5 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.

### 4.5.1 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.

**Q 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 = __________________

**Q 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.

# 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, $f_{sparker} = 20Hz.$.
- 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:

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

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 below). Solving for $v_{1f}$ gives:

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

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

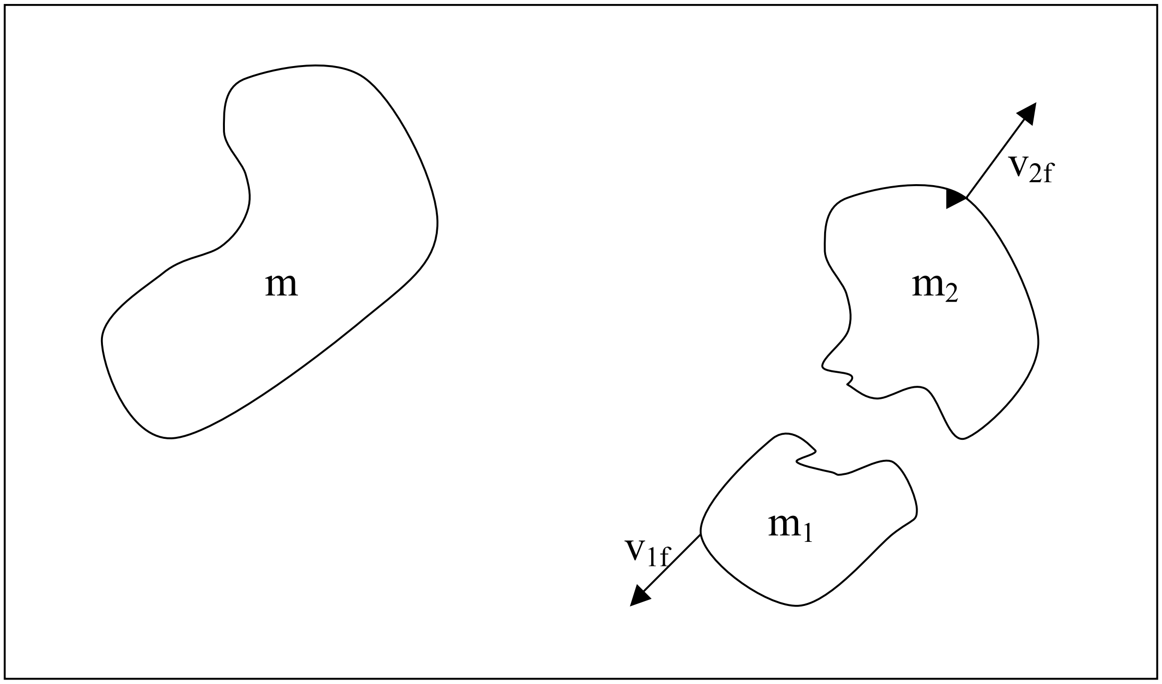



Figure 1: Graphical Portrait of an Explosion

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

**Q 1) Why does the kinetic energy change?**

**Q 2) 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, $\Delta x$ .
- Find their average $\overline{\Delta x}$ .
- Calculate the puck's velocity on the trajectory leg, $v = \dfrac{\overline{\Delta x}}{\Delta t}$ , where $\Delta t = \dfrac{1}{f_{sparker}} = \dfrac{1}{20}\text{sec}.$
- Using your measured values of the puck masses, calculate the magnitude of the puck's momentum,

$$|p| = mv \tag{3}$$

  and the puck's kinetic energy,

$$KE = \frac{1}{2}mv^2 \tag{4}$$

  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 $m_2\vec{v}_{2f_y}{}^{y} = m_2\vec{v}_{2f}\sin\theta_{2f}$ .

### 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 = ______

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

v = ______

|p| = ______

KE = ______

$p_x$ = _______ $p_y$ = _______ $p_x$ =_______ $p_y$ = _______

**Q 3) How well are the before/after *x* and *y* momentum components conserved?**

**Q 4) 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:

$$m\vec{v}_{1i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f} = 0 \qquad (5)$$

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, $\vec{v}_{1f} = \vec{v}_{2f} = \vec{v}_f$ . By conservation of momentum, $v_f$ is along the same path as $v_{1i}$. This gives:

$$m_1\vec{v}_{1i} = (m_1 + m_2)\vec{v}_f \qquad (6)$$

and by rearranging Equation (4) we get:

$$\vec{v}_f = \frac{m_1 \vec{v}_{1i}}{(m_1 + m_2)} \tag{7}$$

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

$$\frac{\Delta KE}{KE} = \frac{KE_i - KE_f}{KE_i} = \frac{\frac{1}{2}(m_1 \vec{v}_{1i}^2 - (m_1 + m_2)\vec{v}_f^2)}{\frac{1}{2} m_1 \vec{v}_{1i}^2} \tag{8}$$

By substituting Equation (7) we have:

$$\frac{\Delta KE}{KE} = \frac{\frac{1}{2}\vec{v}_i^2 \left( m_1 - \frac{m_1^2}{m_1 + m_2} \right)}{\frac{1}{2} m_1 \vec{v}_i^2} = \left( 1 - \frac{m_1}{m_1 + m_2} \right) \tag{9}$$

**Q 5) 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 (5) through (7) to aid your analysis.

*Equal Masses*

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

v = ______ v = ______

$|p|$ = ______ $|p|$ = ______

KE = ______ KE = ______

$p_x$ = ______ $p_y$ = ______ $p_x$ = ______ $p_y$ = ______

**Q 6) How well are the before/after *x* and *y* momentum components conserved?**

*Unequal Masses*

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

v = ______ | v = ______

$|p|$ = ______ | $|p|$ = ______

KE = ______ | KE = ______

$p_x$ = ______ $p_y$ = ______ | $p_x$ = ______ $p_y$ = ______

**Q 7) How well are the before/after *x* and *y* momentum components conserved?**

**Q 8) Calculate the inelasticity for the unequal collision.**

**Q 9) How does the unequal mass affect the momentum and kinetic energy of the pucks?**

**Q 10) 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.

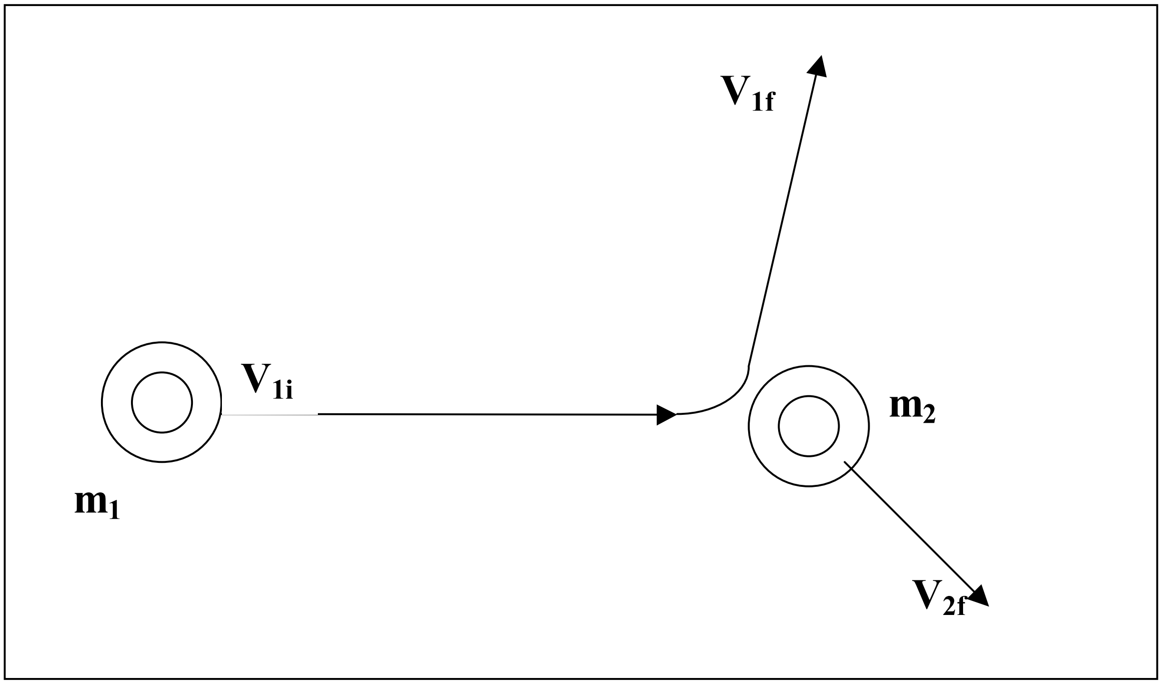



Figure 2: Breakdown of a Collision

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 $v_{1i}$):

$$m_1 v_{1f_x} + m_2 v_{2f_x} = m_1 v_{1i_x} \tag{10}$$

$$m_1 v_{1f_y} = -m_2 v_{2f_y} \tag{11}$$

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

$$\frac{1}{2} m_1 \left( v_{1f_x}^2 + v_{1f_y}^2 \right) + \frac{1}{2} m_2 \left( v_{2f_x}^2 + v_{2f_y}^2 \right) = \frac{1}{2} m_1 \left( v_{1i_x}^2 + v_{1i_y}^2 \right) \tag{12}$$

With a $v_{1i}$ given, Equations (10), (11), and (12) 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:

$$\theta_{1f} = \tan^{-1}\left(\frac{v_{1f_x}}{v_{2f_x}}\right) \quad (13)$$

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 (5) and (10) through (13) to aid your analysis.

*Equal Masses*

*Initial*

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

v = ______

|p| = ______

KE = ______

$p_x$ = _______ $p_y$ = _______

*Final*

Puck #1 $\overline{\Delta x}$ = _______ Puck #2 $\overline{\Delta x}$ = _______

v = _______ v = _______

$|p|$ = _______ $|p|$ = _______

KE = _______ KE = _______

$p_x$ = _______ $p_y$ = _______ $p_x$ = _______ $p_y$ = _______

**Q 11) 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 $\overline{\Delta x}$ = ______ Puck #2 $\overline{\Delta x}$ = ______

v = ______ v = ______

$|p|$ = ______ $|p|$ = ______

KE = ______ KE = ______

$p_x$ = _______ $p_y$ = _______ $p_x$ = _______ $p_y$ = _______

**Q 12) How well are the before/after *x* and *y* momentum components conserved?**

**Q 13) How does the unequal mass affect the momentum and kinetic energy of the pucks?**

**Q 14) 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.

# 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 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 $\omega$ 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.

**Q 1: 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 block 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 block'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 block 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).

**Q 2: 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?**

**Q 3: Did the velocity of the block increase as it slid down the track? Why or why not?**

**Q 4: 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

$$v = \omega r \tag{7}$$

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).

**Q 5: What, if anything, was different about the velocity of the disk compared to the velocity of the "block?" Explain any differences.**

**Q 6: How accurate was the experimental velocity compared to the theoretical value? What was the level of error, and what were possible sources of error?**

**Q 7: What would have happened to your results if you had used a disk with a smaller radius? A disk with a larger axle?**

**PHYSICS 101 LAB EVALUATION**

Name:

Please answer all questions in regards to **LAB 7: CONSERVATION OF LINEAR MOMENTUM** that you preformed in **CLASS**, not for extra credit

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?

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