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Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

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Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

By

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A culminating project submitted to the Department of Education and Human Development of The College at Brockport, State University of New York in partial fulfillment of the requirements for the degree of Master of Science in Education
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

By

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Abstract

Inquiry in the classroom has been interpreted and explained in many different ways. However, at its foundations, inquiry is essentially learning by questioning. In the context of a classroom, inquiry is student lead learning that can occur at various levels of student responsibility. While inquiry based instruction is important in all content areas, this project focuses on using inquiry in the science laboratory.

The benefits of inquiry-based instruction are significant and include increases in student engagement, critical thinking skills, creative problem solving, and autonomy in the learning process. While the benefits of inquiry-based instruction are worthwhile, the challenges of developing and implementing inquiry-based activities may prevent some teachers from shifting their instruction to include a more appropriate level of inquiry. However, the need for an instructional shift toward more effective inquiry-based strategies has become evident, and many teachers have begun to adopt instructional practices which include higher levels of inquiry.

Modifying existing instructional activities to contain higher levels of inquiry is not an easy task. This capstone project has been designed to support science teachers by explaining and demonstrating how to shift their instruction to higher levels of inquiry. The project contains two key components. The first is a chart that was developed to help science teachers identify the current level of inquiry in a given lab activity. The second is a series of “Laboratory Revision Sets” designed to demonstrate how to determine the optimal level of inquiry for a given lab activity and how to modify that lab activity to contain the desired level of inquiry. Teachers can use these two resources to identify the current level of inquiry in their lab activities and modify those activities to contain the optimal level of inquiry for the specific content and context of each lab.
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Chapter 1: Introduction

Rationale

The ever growing amount of scientific knowledge that humanity currently maintains has been achieved through the process of inquiry and collaboration. The ability to think critically and creatively is fundamental to all scientific advancements in the past, present and future. The benefits of thinking critically and creatively to solve problems and gain knowledge are not limited to science or even general academics. They extend into many aspects of daily life. People who are capable of thinking critically and creatively are better equipped to respond to the array of daily choices encountered by a person. It is crucial that all students be taught to think critically and creatively in order to best equip them for independent everyday life. Inquiry-based instruction is an excellent approach to teaching critical thinking skills and creative problem solving while teaching content specific knowledge.

Just the word inquiry seems to mean many different things to many people but generally speaking, it is a student-centered, constructivist approach to learning. Inquiry-based instruction is being adopted by many teachers because it promotes higher levels of thinking and deeper understanding of the curriculum. While traditional instructional methods have their value, inquiry-based instruction is better suited to meet certain instructional goals. Some of the benefits of inquiry are that it increases student engagement, improves critical thinking skills, promotes creative problem solving, and allows for autonomy in the learning process. The need for an instructional shift toward more inquiry-based strategies has become evident and many teachers are adopting instructional practices to include higher levels of inquiry.
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

**Significance**

This project has been prepared to help teachers build better inquiry based lab activities. While it is widely accepted that inquiry-based activities effectively promote higher levels of thinking and deeper understanding, many teachers are unclear on how to modify their current curriculum to include more effective inquiry based instruction. The first step is to identify the current level of inquiry in a given lab activity. Then the teacher must determine what level of inquiry would optimize the student’s learning. Finally, the teacher must modify the existing lab to contain the desired level of inquiry. Chapter three contains a chart to identify the various levels of inquiry and a series of laboratory revision sets which are based on labs currently being used in the Regents physics curriculum. Each set contains the original lab, the rational for change, and the modified lab. Both the “Identifying Levels of Inquiry in the Science Lab” chart and the “laboratory revision sets” provide a model for the process of identifying inquiry levels and modifying inquiry labs.

**Overview of the Following Chapters**

Both of the following chapters deal with the importance of effectively using inquiry in the classroom. The second chapter, the literature review, addresses the importance of shifting instruction toward higher levels of inquiry and provides some support in making this shift. This literature review is provided to support the project which follows in chapter three. The benefits of inquiry, the teacher’s role in inquiry-based instruction, the various levels of inquiry and some examples of inquiry-based instructional materials are all provided in the literature review.

The process of developing inquiry-based activities can be daunting. However, key components of the process are explained in the literature review. One of the important aspects
discussed in this chapter is how to determine the proper level of inquiry based on the content and the context of a given activity. Once the teacher has established this, they can begin to modify their lab activities to align with the desired level of inquiry.

Chapter three, the capstone project, consists of a chart and a series of lab sets which demonstrate how to select the optimal level of inquiry for a given lab activity and how to modify an existing lab so that it contains the desired level of inquiry. To identify the level of inquiry of a given lab activity the “Identifying Levels of Inquiry in the Science Lab” chart is provided. It can be used to determine the level of inquiry based on a few observable features of a lab activity. It is relatively easy to use and accurately describes the various levels of inquiry.

The capstone project also contains a series of “laboratory revision sets.” Each of these sets contains an original lab, a rational for change, and a modified lab. These sets demonstrate the process of modifying a lab activity based on the content and context of a lab by using the observable factors of an inquiry-based activity. This project is meant to serve as a model for science teachers as they apply the principles of inquiry-based instruction in their own classrooms.
Definition of Terms

INQUARY - Learning by questioning, critically thinking and information synthesis.

INQUIRY-BASED LEARNING - Students build their own learning through meaningful activities that are based on the investigation of questions, problems and/or scenarios.

CRITICAL THINKING - Disciplined thinking that is clear, rational, open-minded, and informed by evidence.

LABORATORY - Hands on activities that allow students to develop content knowledge and skills in science such as manipulating variables and analyzing data.

FACILITATOR - Teacher who is responsible to maintain the productive progression of students through the content of an inquiry-based activity.

PROBLEM SOLVING SKILLS - Logical thinking to assess a problem, consider resources, and develop possible solutions.

CONCEPTUAL CHANGE - Modification of how someone understands something, usually caused by new observations or new viewpoints which challenge the validity of a person’s prior knowledge.
Chapter II: Literature Review

Overview

The purpose of this literature review is to make a case for shifting instruction toward higher levels of inquiry and to provide some support in making this shift. This will be accomplished by addressing the benefits of inquiry, the teacher’s role in inquiry-based instruction, the various levels of inquiry and some examples of inquiry-based instructional materials. The project to follow this literature review will focus specifically on shifting labs to higher levels of inquiry in order to improve student learning.

Properly implementing inquiry based instructional activities can be challenging for many reasons. It is difficult for teachers to shift responsibility on to the students’ shoulders and to facilitate multiple learning paths simultaneously. Determining the proper level of inquiry to implement and developing materials to do so is also a challenging task. The content of this literature review and the materials presented in the final project will support science teachers as they modify their lab activities to include more appropriate levels of inquiry.

History and Theoretical Framework

Inquiry gained attention in science education partially due to its prominence in the National Science Education Standards in 1996. These standards described inquiry as a step beyond conducting science as a step by step process. Inquiry was to be implemented to help students understand the nature of science and why we know what we know about science. The intention was to help students, in all grade levels and domains of science, gain the skills necessary to investigate the natural world independently. Through inquiry, students should be
asking questions, designing and conducting experiments, gathering data, thinking critically, relating evidence, developing possible explanations, and forming scientific arguments. The purpose of including inquiry in the National Science Education Standards was to prepare students who understand the process of science and can independently apply it to the natural world.

In April of 2000, the National Research Council published a guide for implementing inquiry-based instruction aligned with the National Science Education Standards. The authors outlined five essential features of science inquiry. These included learners being engaged with scientific questions, assessing evidence, developing possible evidence based explanations, evaluate alternative explanations and justifying their final proposed explanation (Olson, 2000). Inquiry soon became a widely known term with a wide range of meanings and methods of implementation.

The term “inquiry” was essentially replaced by a set of more descriptive components called “practices” in the Next Generation Science Standards (NGSS)(NRC, 2013). The Framework For K-12 Science Education, which was the foundation for NGSS, lists eight practices of science and engineering that all students should learn. The eight practices includes: asking questions, developing models, planning and conducting investigations, analyzing data, thinking mathematically, constructing explanations, engaging in evidence based argument, and evaluating and communicating information. While the word “inquiry” has been replaced, the values of inquiry-based instruction, which were originally promoted by the National Science Education Standards, remain foundational to the NGSS.

Inquiry-based instruction falls under the Constructivism learning theory. Constructivism is based on the idea that learners construct their knowledge from observations and from prior
learning. The words construct, constructivist and constructivism are used to describe learning activities where students build their knowledge through experiences and reflection on those experiences. Inquiry is closely intertwined with constructivism because inquiry-based activities are intended to promote student-lead information synthesis. Inquiry-based instruction is supported by the constructivist view that the human brain naturally works to understand what it observes by making connections with prior learning and by looking for patterns (Lew, 2010). Teachers who develop inquiry-based instruction do so with the goal of supporting students as they construct their own learning.

He (2013) describes constructivist instruction as a method of teaching science through discovery, and inquiry including problem-based inquiry, project-based inquiry, context-based inquiry, and resource-based inquiry. The types of inquiry listed are only different mediums by which the inquiry process occurs. Inquiry is the process of learning through questioning, critical thinking and information synthesis. So, constructivism is essentially learning through discovery, questioning, critically thinking and information synthesis.

Constructivism also relies heavily on the students’ ability to build their own understandings on the foundations of prior knowledge (Lew, 2010). Another important aspect to inquiry and constructivism is the level of responsibility placed on the student. Lew describes constructivism as a process involving active participation among the students. The students take on the role of “active sense-makers” who are looking to build accurate and comprehensive knowledge about the topic at hand (Patterson, 2011). Constructivist instruction is designed to put more responsibility for the learning process on the shoulders of the student. With various levels of guidance from the teacher and support form classmates, a student does the majority of the work required to build their own knowledge of the content.
There have been many modern day pushes for educational reform to promote deeper learning through more rigorous standards. The reason for these reforms is that more jobs demand more advanced skills. In order to be successful in today’s global economy, students will need to become decisive data interpreters and innovative thinkers (Sundberg, 2013). Today’s students will need to be able to think critically, solve problems, reason and make decisions once they reach the work force. For this reason, students need to be involved in real learning that improves their ability to think about and apply scientific knowledge instead of just memorizing and regurgitating scientific facts and processes (Lew, 2010). Constructivism and inquiry-based instructional methods can help student learn to think at the higher levels required to prepare them for the work force. Teachers trained in constructivism should be able to promote and support certain aspects of the inquiry process in their classrooms.

**Educational Benefits of Science Inquiry Instruction**

Learners of all ages and abilities can benefit from inquiry-based learning in the science classroom. Traditional methods of science instruction tend to be teacher centered and limit the potential for higher levels of thinking. For example, in a traditional physics classroom, students receive direct instruction and are only required to reproduce the content. This format often requires students to memorize, understand and apply the content. However, inquiry-based learning requires students to invest more in the learning process as they analyze, evaluate and create their own learning.

Inquiry-based instruction has proven to be effective at various instructional levels. Cabe-Trundle (2010) demonstrated that guided inquiry is more effective than traditional instruction in promoting conceptual change and a more accurate scientific understanding among middle school
students. An inquiry based lab activity was used to guide students as they constructed their own knowledge about the phases of the moon by making observations, looking for patterns, discussing, and modeling the phases.

At Georgia Southern University, Physics professors implemented a trial course design in Physics one and two to observe the potential benefits of inquiry. They implemented inquiry labs, a combined lab lecture setting, and the professor took on the role of a facilitator. After observing an increase in achievement of targeted instructional outcomes, the department decided to shift the instruction of all physics one and two courses from a traditional lecture format to a more inquiry-based studio format (Gatch, 2010).

There are many benefits to inquiry-based instruction. Millett (2012) determined some of the benefits to be an increase in critical thinking skills, class participation and creativity in problem solving. Both studies conducted by Gatch (2010) and Cabe-Trundle (2010) found that inquiry based processes led to a deeper level of content knowledge and scientific skills. In addition to these benefits, students also reported more favorable attitudes toward the class and the content as a result of a shift toward inquiry learning (Gatch, 2010). A study described by Madhuri (2012) found that students who participated in inquiry-based labs had a greater appreciation for the relevance of the concepts and performed better on a posttest than those who received the traditional conformation lab.

Another benefit of inquiry is that the learners use metacognition as they assess data to determine if their current understanding fits their observations. This process drove conceptual change and enabled students to see how and why certain scientific concepts are accurate. Cabe-Trundle (2010) specifically indicated that guided inquiry instruction promoted conceptual change and improved the students’ problem solving skills.
It was found that the teachers who delivered inquiry-based instruction asked twice as many open-ended questions as the teachers in the control group and class participation increased by fifty percent. Also, the students who received inquiry-based instruction scored higher on cognitive ability tests. As a whole, students receiving inquiry-based instruction improved their problem solving skills and their willingness to participate with peers in instructional activities.

Properly implemented inquiry-based learning promotes curiosity, builds critical thinking skills, improves problem solving skills, drives conceptual change and helps students construct their own learning. The skills developed through inquiry-based instruction prepare students to be scientifically literate adults capable of investigating the natural world. Inquiry-based instruction also prepares students with the skills they need to be successful in science and engineering related fields.

Inquiry-based learning will help prepare students for employment in the fields of math and science. As students learn through questioning and synthesizing information they will sharpen their critical thinking skills and prepare themselves for the challenges of working in any job which relies on math and science. The benefits of inquiry-based learning are significant and should be made available to all science students.

The Teacher’s Role in Inquiry-Based Instruction

The role of the teacher during inquiry-based instruction is that of a facilitator. Instead of delivering content in the form of a lecture, content knowledge is gained through discussions and group work. In an inquiry-based teaching environment, it is the teacher’s role to provide the questions which will prompt student learning and engagement. Schneider (2013) described the
challenges of the shifts in responsibility of a teacher. Instead of preparing a lecture designed with a linear presentation of content, teachers are responsible to develop open ended questions and materials that will initiate the learning process.

Different students approach new content in different ways so the teacher’s role is to facilitate the multiple paths which will be taken by the students as they move toward a common learning objective. Developing questions, anticipating learning paths, and accommodating those learning paths are part of the challenge of inquiry-based instruction. Giving up some control of pacing and method in which information is learned can be one of the major challenges for teachers who are comfortable with the traditional lecture-based approach. In a teacher-centered classroom the teacher has full control of the progression, method and pace of the content. However, in a student-centered, inquiry-based classroom the teacher must be willing to give up total control over the method, pacing and order of concept progression. With all students learning the same content in different ways, the teacher must become comfortable with allowing students to learn and make mistakes in ways that the teacher would not have allowed in a traditional lecture.

Another challenge of inquiry-based instruction is to keeping students moving efficiently through their various learning paths. The higher the level of inquiry, the greater the level of student autonomy and it is important that the teacher can keep the students progressing through each of their individual learning paths at an appropriate and efficient pace. Instead of providing students with step by step directions to achieve an objective, the teacher needs to present the objective in the form of a relevant question and provide access to the resources and skills necessary to achieve the objective through one of many learning paths (Schneider, 2013). While the teacher’s role is that of a facilitator, it is the student role to construct their own knowledge from the questions, materials and discussions provided by the teacher.
Some teachers may use the 5E strategy as an effective way to implement an inquiry-based, method of instruction (Keser, 2010). Whatever strategy teachers decide to use, it is important that teachers allow student autonomy and initiation in the learning process. This would allow students to drive the lesson and promote more interaction between students and the teacher. Inquiry-based instruction also calls for teachers to develop meaningful open-ended questions to direct the learning and expose misconceptions which can then be remedied. To motivate learners in this process learning activities should be related to the students’ interests and the students should be given opportunities to make decisions in the learning process which will give them a sense of control over their learning (Patterson, 2011).

Another important point to mention is the need for differentiated instruction during the inquiry process. Students will undergo conceptual change and progress through the activity in different ways. In order to accommodate these students, the teacher will need to be prepared to provide the necessary scaffolding for success with the inquiry-based activity. Longo (2011) elaborated on this aspect of inquiry-based instruction and gave the example of providing a checklist of things to include in a procedure to help the student as they begin writing their own procedure. Longo also added that the best way a teacher can learn to do inquiry is to try it and reflect on it afterwards.

A well built inquiry-based activity will engage students with relevant scientific questions and require students to develop explanations using evidence from the lab. Inquiry labs should also give students the opportunity to evaluate their explanation against alternate explanations and require students to justify their explanation (Banerjee, 2010). These elements of an inquiry lab promote the use of higher order thinking skills and deeper understanding of the content. Another factor to be considered when designing inquiry-based activities is the level of difficulty provided
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by the learning task. An appropriate level of difficulty will allow students to experience success in the learning process. These are some of the ways in which a teacher can help prepare students for the demands of the ever increasingly complex skill set required by modern jobs.

The teacher’s role varies depending on the level of inquiry. During a guided inquiry lab the teacher’s role is to maintain the progress and accuracy of each lab so that students are prepared for the subsequent content (McDermott, 1996). During an open/authentic inquiry lab the teacher’s role is to facilitate the development of the students’ questions and procedures (Zion, 2012). A lab at this level of inquiry is very beneficial to the students in building their critical thinking skills and their depth of content knowledge.

When designing an inquiry-based lab, the teacher should build in activities that promote conceptual change (Pryatt, 2012). This can be done by carefully selecting activities that will reveal evidence which will oppose the student’s misconceptions. This will force students to synthesize their prior knowledge with the new evidence in order to refine their understanding of the content.

It is the responsibility of every science teacher to develop a science curriculum which draws on the various levels of inquiry to improve students’ ability to think critically and their knowledge of the content. Properly implemented inquiry-based learning promotes curiosity, builds critical thinking skills, improves problem solving skills, drives conceptual change and helps students construct their own learning.

There are various levels of inquiry which can be implemented to maintain an acceptable balance between the pacing efficiency of a teacher-centered approach and the depth of learning achieved in a student-centered approach. It is the responsibility of every science teacher to develop a science curriculum which draws on the various levels of inquiry to improve students’
ability to think critically and their knowledge of the content. Determining the correct level of inquiry to use for each area of the content is challenging. The two main factors to consider are the nature of the content and the context of the content. The nature of some content, such as equation development, lends itself well to being tested and manipulated while other content, such as classifying subatomic particles, is better delivered in direct instruction. The context of the content refers to all of the factors surrounding the content such as classroom culture, learning styles, diverse ability levels, students’ background knowledge and the students’ prior experience with inquiry based activities.

Levels of Inquiry

While Inquiry learning is becoming a highly advocated learning principal it is not a one size fits all solution in education. The correct level of inquiry instruction is very important. In fact, the correct balance of doing science, inquiry instruction and direct instruction can be effective and maximize the respective advantages of each style of instruction (He, 2013). In order to determine the correct balance of the various instructional methods, teachers must first consider the nature of the content. More substantial portions of conventional instruction may be more effective in well structured domains such as math and physics, while a focus on constructivist instruction and inquiry may be more effective in less structured domains such as medical case studies (He, 2013). While the examples provided by He are narrow, it is clear that teachers must balance instructional methods based on the nature of the content.

There are many different systems for classifying the level of inquiry in a lab. Nivalainen (2013) divides the levels of inquiry into 4 categories which are verification, structured, guided, and open. Verification isn’t necessarily considered inquiry but it is the way many labs are
currently done and it gives the spectrum of inquiry levels a zero point. In structured inquiry, the students are provided with the problem, apparatus and procedure. They are only required to follow the steps and find an answer. In guided inquiry, the problem and materials are provided, but the students must develop the procedure and find the answer. Open inquiry allows students to develop a question and procedure on their own. Only the materials they request are provided by the teacher (Nivalainen, 2013). This uppermost level of inquiry is only beneficial with the correct content and context. It is not the best way to learn all content areas. It is the teacher’s responsibility to figure out how to implement the various levels of inquiry across their curriculum to implement the best practices for the course. It is important to use all the levels at different points in the year because each level provides different benefits. The efficiency and consistence of a verification lab may be important for one topic while the critical thinking skills and concept synthesis skills exercised during an open inquiry lab may fit well with another concept.

There is a spectrum of instructional styles which ranges from teacher-centered to student-centered. Teacher-centered classrooms are more traditional and lecture-based. In a teacher-centered-classroom the students spend the majority of class time observing the teacher’s demonstrations and descriptions of the content. Student-centered classrooms, on the other hand, tend to be more interactive. In a student-centered classroom, students spend the majority of class time discussing and working with the content directly. This spectrum of instructional styles can be closely aligned with an inquiry spectrum.

There are various levels of inquiry which can be implemented to maintain an acceptable balance between efficiency and deeper exposure to the content. The different levels of inquiry were described by both Zion (2012) and Buck (2008). There were subtle differences in the authors’ descriptions of the inquiry spectrum. For example Zion described 3 levels of inquiry
while Buck stretched the spectrum to contain five levels of inquiry. The names and descriptions of the levels varied as well. What Zion described as “Open inquiry,” Buck described as “authentic inquiry.” In spite of these minor differences, both systems for describing the levels of inquiry can be useful for revealing the current level of inquiry for any given science activity. The rubric presented in Buck’s article described how to identify the level of inquiry that a certain lab activity contained. The rubric had been used on over 20 lab manuals and found that the majority of undergraduate labs are designed at low levels of inquiry.

Both Zion (2012) and Buck (2008) call upon educators to shift instruction toward higher levels of inquiry. This can be done in a laboratory setting by modifying the labs to contain fewer step by step instructions and giving more responsibility to the students to develop the various components of the lab, such as the procedure. It is natural for educators to want more control over the learning process and they achieve this by using the lower levels of inquiry such as conformation, structured inquiry and guided inquiry. However the development of critical thinking skills occurs at the higher levels of inquiry. In open inquiry students are provided with the question and background information but they develop their own procedure. In authentic inquiry, the students asked to develop their own question, background information and procedure. This level of inquiry exposes students to the true nature of science and requires them to think critically and creatively.

Zion (2012), Buck (2008) and Brown (2008) all promoted the use of higher levels of inquiry in the science classroom. Open/Authentic inquiry is the highest level of inquiry in which the students decided what question to ask and how to proceed. This level of inquiry is usually inductive by nature and the most challenging level of inquiry for students (Mandrin, 2009). One example of open/authentic inquiry in physics can be found in a summative activity based on a
unit of instruction about work, power and energy. Students learning within the conceptual framework of work, power and energy can develop a question such as “how many calories do I burn by walking up stairs?” or “how powerful must a vehicle be to accelerate at a certain rate?” Then, students can develop and conduct a procedure to answer their question.

Unfortunately, many labs provide detailed instructions which direct students, one step at a time, through an experiment. The problem with these traditional labs is that they are preparing students to think like lab technicians, not like scientists (Polacek, 2005). These highly structured labs are designed for the purposes of confirming the content which was taught in a lecture and for teaching the technical skills needed to conduct an experiment. While these two purposes for a lab are valid, labs can be more effective instructional tools if they are adapted to become more inquiry-based. Inquiry is a student-directed way of studying science in which the students construct their own knowledge by gathering and analyzing evidence (Nivalainen, 2013). By selecting the correct level of inquiry for a particular lab, students will develop their content knowledge and skills.

McDermott (1996) presents an entire physics curriculum’s worth of guided inquiry style labs designed to promote critical scientific reasoning skills. Using content narratives, conceptual questions, lab activities, teacher checks and practice problems, McDermott guides the students through step-by-step lab procedures which allow students to construct their own learning. This would be classified as a form of guided inquiry according to Buck’s (2008) rubric. An important part of McDermott’s approach is the built in teacher checks which maintain the accuracy of the content knowledge gained in each lab. The physics content builds from simple to complex and students are dependent on prior content to understand increasingly complex concepts. In
McDermott’s model the students construct their own learning using guided inquiry labs and the teacher facilitates and maintains the learning process.

According to Nivalainen (2013), labs in higher levels of inquiry help students better understand the content, gain a better understand of laboratory skills and improve their investigative skills. In a conformational lab, students follow the steps outlined and look for the expected result. This often requires little understanding of how things actually work. However, in a guided inquiry lab, students must develop their own procedure. In order to do this, students must develop a working understanding of the content as well as an understanding what various laboratory procedures are for and why they are used. Students also gain investigative skills as they take the lead on developing possible procedures and solutions to the question posed at the start of the lab. Students enjoy the autonomy that comes with the higher levels of inquiry. Pryatt (2012) found during research that what students enjoy most about hands on labs is the chance to explore and manipulate the variables of an experiment. The self-directed nature of inquiry-based labs allows for this exploration.

**Summary and Connection to the Capstone Project**

The appropriate level of inquiry is different for different labs. The teacher must decide what level of inquiry will maximize the instructional value of the lab based on the content and the context (Nivalainen, 2013). The content of some labs lends its self well to higher levels of inquiry. A lab intended to reveal a pattern of develop an equation may work well as an inquiry lab. However, a lab on highly conceptual content, such as modern physics, may be more productive at lower levels of inquiry. The context is also important as there are many factors surrounding instruction that must be considered by the teacher. The teacher must consider the
students’ background knowledge of the content, their ability to work in groups, their ability to be self-directed, and many other factors. These factors play a significant role in selecting the appropriate level of inquiry for individual groups of students. With the right level of inquiry, students will gain a deeper understanding of the content and grow in their ability to conduct scientific investigations (Blanchard, 2009).

Modifying existing confirmation labs to contain higher levels of inquiry is not a terrible difficult thing to do. By using an inquiry level assessing guide, such as the one described by Nivalainen (2013), teachers can determine the level of inquiry of a given lab and then modify it to be at a higher level. Just by having the students develop their own procedure; the teacher has increased the level of inquiry and in turn increased the level of thinking. It is important to remember that more inquiry is not always best. Teachers need to find a balance that works best for the nature of the content and the students. The following chapter provides examples of how to determine an appropriate inquiry level and how to modify existing labs to contain the desired level of inquiry.

The main implication for science teaching is that teachers should find an appropriate balance of methods for delivering content to their students. Yes, teachers should include the strategies and methods associated with constructivism and inquiry but they should not abandon direct instruction and forgo its advantages such as a clear explanation in a timely manner. All of the content taught across the science classes has different attributes by nature and it is the teacher’s responsibility to develop a curriculum which maximizes the positive aspects of the various instructional methods. A teacher should not fully omit all elements of direct instruction. Instead, she must strike a balance which works for each unit in her curriculum. Some units may by nature lend themselves to a more inquiry-based approach while others will be more dependent
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on the clarity and linear style of direct instruction. Both Patterson and He addressed the value of mixing instructional methods to optimize results in student learning and retention of the content. Preparing and delivering the correct balance of instructional methods is essential the effectiveness of instruction. The following chapter demonstrates how to select and develop the optimal inquiry level for various concepts taught in the regents physics laboratory.
Chapter III: The Capstone Project

Overview

This chapter contains materials that can be used to identify the level of inquiry of a given lab activity and a series of “laboratory revision sets” which demonstrate the process of modifying a lab activity. The “Identifying Levels of Inquiry in the Science Lab” chart is a quick reference guide to determining an inquiry level based on a few observable features of a lab activity. The chart was synthesized using several sources which described and identified the components of the various levels of inquiry. The four basic levels of inquiry identified in the chart are conformation, structured, guided and open. The five characteristics used to describe each level of inquiry are the question, the background, the procedure, the results analysis and the conclusion. A lab activity can be assigned a specific level of inquiry by identifying what characteristics are provided to the student by the lab activity. As a general rule, the fewer the number of characteristics provided, the higher the level of inquiry. The first step in revising a lab is to identify its current level of inquiry and this can be accomplished by using the “Identifying Levels of Inquiry in the Science Lab” chart.

The bulk of this chapter consists of a series of “laboratory revision sets.” Each of these sets contains an original lab, a rational for change, and a modified lab. The original lab is the lab that is being used or has been used in the past in a Regents physics classroom. The first step is to assess the original lab using the “Identifying Levels of Inquiry in the Science Lab” chart. Once the original inquiry level is identified, the appropriate inquiry level must be determined based on the content and context of the lab. Once the appropriate level of inquiry has been determined, changes can be made to produce the modified version of the lab. The reasoning for why the lab needs to be changed and some specific details about the changes that were made are described in
the rational portion of the lab set. Both the chart and the lab sets are designed to guide the process of identifying inquiry levels and modifying labs.

**Project Design**

This project is intended to accomplish two goals. The first goal is to develop a system for identifying the level of inquiry in a given activity. The second and more demanding goal is to shift the current level of inquiry in a given lab activity to a more appropriate level of inquiry. Many of the labs currently used in Regents physics are designed at lower levels of inquiry and will likely need to be shifted to higher levels of inquiry. Once the labs have been modified, the students will reap the benefits of appropriately leveled, inquiry-based instruction.

This project is designed to shift the level of inquiry in the physics lab from lower conformational levels of inquiry to higher authentic levels of inquiry. By making these changes in the physics lab, students will strengthen their content knowledge and sharpen their critical thinking skills. For example in a lab about gravity the expected results will be removed and the responsibility of data analysis will be placed on the students. This will shift the lab from being a conformational lab to a structured inquiry lab. This example is included in the following pages. The first lab, titled “Free Fall Motion (Original)” is the conformational lab and the second lab titled “Free Fall Motion (Modified)” is the structured inquiry lab.

One of the anticipated challenges will be in assessing the effectiveness of making these shifts in inquiry. Most of the literature that was reviewed used a control group who received traditional instruction. Many of the results were based on student interviews making them qualitative in nature. The quantitative results that were presented were based on posttests that assess content knowledge. This is a problem because the real benefit to inquiry-based instruction
is that it strengthens students’ critical thinking skills and ability to apply the process of science to real world problems. Increased content knowledge is a benefit but not the primary benefit.

There are several options for assessing how much students increase their ability to think critically and apply scientific processes. This project will assess these two factors by comparing lab scores over the course of the school year. As the year progresses, labs of equivalent levels of inquiry will be compared to see if students are improving their inquiry based abilities. For example, open inquiry labs are supposed to increases the students’ abilities to design and conduct experiments. If this is true, then the experiments designed and conducted by students at the end of the school year should be more comprehensive, and therefore receive higher scores, than the experiments designed and conducted at the start of the year.
Levels of Inquiry Identifier

There are several ways of classifying the various levels of inquiry in the science laboratory. Pictured below is the “Identifying Levels of Inquiry in the Science Lab” chart. This chart was created by synthesizing descriptions of the various inquiry levels from multiple sources and it represents a common view about the description of each inquiry level.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Conformation Level 0</th>
<th>Structured Inquiry Level 1</th>
<th>Guided Inquiry Level 2</th>
<th>Open Inquiry Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Not Provided</td>
</tr>
<tr>
<td>Background</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Not Provided</td>
</tr>
<tr>
<td>Procedure</td>
<td>Provided</td>
<td>Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
</tr>
<tr>
<td>Results Analysis</td>
<td>Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
</tr>
<tr>
<td>Conclusion</td>
<td>Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
</tr>
</tbody>
</table>

This chart most closely resembles the chart presented by Buck (2008) in the sense that it identifies laboratory inquiry levels based on what is provided to the students by the teacher in a given lab activity. The purpose of this chart is to help science teachers identify the current inquiry level of a given lab activity and provide insight about how to adjust the level of inquiry. For example, if it is determined that the original lab activity was a structured inquiry lab, the teacher may decide to turn it into a guided inquiry lab by requiring the students to develop their own procedure.

It should be mentioned that the inquiry level of some lab activities may be more difficult to identify due to scaffolding, an abnormal lab structure, or other factors. For example, a lab
designed to scaffold the process of procedure writing might provide the students with a bank of possible procedural steps instead of having the students develop a procedure on their own. In this example the lab activity would be somewhere between structured and guided inquiry. While some labs will fall between the levels of inquiry, the vast majority of labs will likely be identified as a specific level. In either case, the process of identifying the current level of inquiry and modifying the lab is the same.

**Laboratory Revision Sets**

The following pages contain “laboratory revision sets.” The first page of each set provides a rational for the changes that are required to build a more effective inquiry-based lab. This is followed by the original lab which has been traditionally used in the regents physics classroom. Finally, the modified lab is presented which has been adapted to deliver a more appropriate level of inquiry instruction based on the rational.

The rational is based primarily on the nature of the content and the context of the content. When assessing the nature of the content, consider what skills the students will need and what connections they’ll have to make in order to achieve the learning objective. If these skills and connections can be developed efficiently, without explicit instruction, then the content is well suited for higher levels of inquiry. When assessing the context of the content, consider all of the factors surrounding the content such as learning progression, classroom culture, learning styles, ability levels, background knowledge and the students’ prior experience with inquiry-based activities. The rational section of each “laboratory revision set” will consider both the nature and context of the content. The following table contains a list of the “laboratory revision sets.”
### Table 1. Laboratory Revision Sets

<table>
<thead>
<tr>
<th>Set Number</th>
<th>Topic</th>
<th>Revision</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gravity</td>
<td>Conformation to Structured</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>Air Resistance</td>
<td>Conformation to Structured</td>
<td>32</td>
</tr>
<tr>
<td>3</td>
<td>Centripetal Force</td>
<td>Conformation to Structured</td>
<td>41</td>
</tr>
<tr>
<td>4</td>
<td>Angled Projectile Motion</td>
<td>Conformation to Structured</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>Impulse</td>
<td>Conformation to Structured</td>
<td>58</td>
</tr>
<tr>
<td>6</td>
<td>Projectile Motion</td>
<td>Structured to Guided</td>
<td>63</td>
</tr>
<tr>
<td>7</td>
<td>Springs</td>
<td>Conformation to Structured</td>
<td>71</td>
</tr>
<tr>
<td>8</td>
<td>Waves</td>
<td>Conformation to Structured</td>
<td>79</td>
</tr>
<tr>
<td>9</td>
<td>Light</td>
<td>Conformation to Structured</td>
<td>87</td>
</tr>
<tr>
<td>10</td>
<td>Power</td>
<td>Structured to Guided</td>
<td>95</td>
</tr>
<tr>
<td>11</td>
<td>Vectors</td>
<td>Structured to Guided</td>
<td>102</td>
</tr>
<tr>
<td>12</td>
<td>Static Electricity</td>
<td>Conformation to Structured</td>
<td>111</td>
</tr>
<tr>
<td>13</td>
<td>Friction</td>
<td>Structured to Guided</td>
<td>117</td>
</tr>
<tr>
<td>14</td>
<td>Simple Harmonic Motion</td>
<td>Structured to Guided</td>
<td>126</td>
</tr>
<tr>
<td>15</td>
<td>Mechanics</td>
<td>Guided to Open</td>
<td>135</td>
</tr>
</tbody>
</table>
Laboratory Revision Set 1

**Topic**: Gravity

**The Original Lab**: “Free Fall Motion (Original)”

This lab has been identified as a conformation lab because the question, background, procedure, results analysis and conclusion are all provided to the students in the lab.

**Rational for Change:**

The shift from the conformation level to the structured inquiry level has been made because providing the results analysis and conclusion is not necessary to the success of the instruction. The nature of the content is such that students are able to analyze the data independently and draw their own conclusions without direct instruction from the teacher. The context of the content does limit shifting to higher levels of inquiry primarily because this lab is conducted early in the school year and students have little experience with inquiry.

**The Modified Lab**: “Free Fall Motion (Modified)”

It has been modified to be a structured inquiry lab by requiring the students to analyze the results and develop their conclusions independently. In addition, students must then apply the process they learned to a new situation in order to calculate their reaction time. The reaction time portion of the lab serves two purposes. First, it requires students to use the exact same process and equation they just learned to solve a new type of problem for a different variable. This extends and solidifies their concept of free fall motion and distance covered while accelerating. Secondly, it serves as a way to differentiate the instruction. A strong lab team can complete this section for each of its members, while a struggling lab team could skip the reaction time section of the lab and spend more time on the fundamental concepts being taught in the main portion of the lab.
Introduction:

Galileo reasoned that all objects should fall with the same uniform acceleration independent of their mass. It is said that Galileo conducted experiments from the leaning tower of Pisa to verify this hypothesis, but this is not likely to be true. The hypothesis that objects should fall with uniform acceleration was not one that could be easily verified at the time, due to the limited nature of timekeeping devices. In fact Galileo verified his hypothesis indirectly by examining the motion of balls rolling down inclines—a method that was less glamorous but more effective.

In this lab we will attempt to verify the hypothesis directly by dropping balls of clay and timing their fall using stopwatches.

When a body falls from rest through a distance \( d \) in time the relationship between the variables \( d \) and \( t \) depends on the nature of the motion. If the motion is uniformly accelerated motion then the following relationship holds

\[
d = \frac{1}{2} g t^2
\]

The purpose of this lab is to verify the above relationship using graphical analysis and to determine an experimental value of the acceleration due to gravity \( g \).

Materials:

- Stopwatch
- Tape measure
- Play-Doh

Procedure:

1. Make two different size Play-Doh balls and drop them from the same height.
2. Record what you observed.
3. Combine the two balls to make one large ball.
4. Drop the ball from different heights. Repeat twice
5. Record the height and amount of time it takes to travel that time.
6. Using your data plot a graph of \( dvst^2 \). (If the motion is uniformly accelerated the resulting graph should be linear.)
### Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

<table>
<thead>
<tr>
<th>Distance of Dropped Ball (d)</th>
<th>1 m</th>
<th>2 m</th>
<th>2.5 m</th>
<th>3 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Trail 1 (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Trail 2 (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculate (t²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Graph (d) vs. (t²)

Slope of Graph 1 = _________________

Conclusions/Questions:

1. When you dropped the two balls of Play-Doh did they land at the same time? Does the mass of an object matter when it is freefalling? Why?:

2. What does your graph tell you about gravity:

3. Compare your slope with the accepted value for g. Do they differ? Why or Why not
Free Fall Motion (Modified)

Purpose:

Gravity is the force that pulls masses together. Find the acceleration caused by the force of gravity on objects in free fall.

Procedure:

1.) Drop objects from the roof of the school and time how long they take to fall to the ground.
2.) Calculate the acceleration of each object.

<table>
<thead>
<tr>
<th>Object:</th>
<th>1. Bowling Ball</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
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<tr>
<td>Trial 3</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Trial 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Distance of drop = __________ Initial Velocity = __________

What is the acceleration, which was caused by the force of gravity, of each object?

Show you work below.

<table>
<thead>
<tr>
<th>1. Bowling Ball</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
</tr>
</thead>
</table>
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

What was the average acceleration caused by gravity?

Do all objects accelerate at the same rate? Explain why or why not using some sort of proof from the lab?

What is the percent error compared to the given acceleration caused by gravity on the reference table?

What are some reasons our results weren’t completely accurate?

**Reaction Time**

**Procedure:**

3.) Hold a meter stick between your partner’s fingers and drop it.

4.) The partner being tested must catch the meter stick as quickly as possible.

What is the distance the stick fell ________ ? (in meters)

Explain how can you calculate your reaction time?

Calculate your reaction time below.
Laboratory Revision Set 2

**Topic:** Air Resistance

**The Original Lab:** “Air Resistance (Original)”

This lab has falls somewhere between the conformation level and the structured inquiry level. This is because the question, background and procedure are provided; and the results analysis and conclusion are partially provided. For example, in 4th step of the Data Analysis section, the students are told what the graph of their data should reveal.

**Rational for Change:**

The shift from the conformation level to the structured inquiry level has been made because removing the partially provided conclusion requires the students to think more critically as they analyze their data and develop the conclusion independently. The nature of the content lends itself well to student analysis and conclusion development because the data being collected is very reliable and the plotted data points reveal a clear pattern. The context of the content also supports this level of inquiry because at this point in the curriculum students are familiar linear and exponential graphs that represent motion so most students will be able to identify these patterns independently in the lab setting. However, a guided inquiry lab would be less beneficial because at this point in the curriculum most students do not contain the background knowledge required to design their own procedure to identify the relationship between air resistance and velocity.

**The Modified Lab:** “Air Resistance (Modified)”

This lab has been modified to be a structured inquiry lab by requiring the students to analyze the results and develop their conclusions independently. This can be seen in questions 5 and 10 where students have to analyze their graphed data, recognize the mathematical
relationship it reveals and write an equation to represent the relationship of the two variables. By making this modification students will learn to independently analyze their data and draw their own conclusions. This will require the students to think at higher levels and have more meaningful interactions with the content which causes a deeper understanding and better retention.
Air Resistance (Original)

**Purpose:** To determine the mathematical relationship between the force of air resistance acting on a moving object and the object’s velocity.

**Equipment:** 6 coffee filters, stopwatch, Meter sticks

**Theory:**

As an object falls through the air, two forces act on the object, the object’s weight and the force of air resistance. For many objects, such as a slow moving object, the force of air resistance is small enough that it can be ignored. However, for objects of very small mass or objects moving at high speeds air resistance is far from negligible.

In this lab you will look at the effects of air resistance on paper coffee filters. Since these filters are extremely light, (0.9 grams), air resistance has a noticeable effect.

At the instant the filter is dropped, its initial velocity is zero and the only force acting on it is its weight. As the filter increases in speed the force of air resistance on the filter also increases. Eventually, the force of air resistance exactly equals the weight of the filter. This is called equilibrium. At this point the net force acting on the filter is zero ($\Sigma F = 0$). According to Newton’s First Law of Motion, when the net force acting on an object is zero, the object will be either at rest or moving at a constant velocity. This velocity is referred to as the object’s terminal velocity.

If you change the weight of the filter, the terminal velocity will be reached when the force of air resistance equals this new weight. By changing the weight of the filter you can observe the relationship between the force of air resistance and the velocity of the object.

**Directions:**

1) Tape two meter sticks together to make a double meter stick. And mount this vertically to the side of the table with one end touching the floor.

2) Start out with 6 coffee filters nested together.

3) Hold the filters at least 0.5 meters above the top of the double meter stick. Release the filters. As the filters pass the top of the double meter stick begin timing their decent and stop timing when they hit the floor. Record your time and the mass of the coffee filters.

4) Repeat this procedure four additional times with the same number of filters.

5) Remove the inner most filter (this keeps the surface presented to the air the same throughout the lab) and repeat steps 3 through 4.
6) Continue to remove one filter at a time, timing their fall, and repeating steps 3 and 4.

Data Analysis:

1) Determine the average time of fall for each number of filters. Record your data in a table and attach it to this lab.

2) Since you may assume the filters are falling at a constant velocity (terminal velocity) over the 2 meters, you can calculate their average speed. Determine the terminal velocity for each trial. Show your work below.

3) Since the force of air resistance and the weight of the filters are equal if the object is falling at terminal velocity we can calculate the force of air resistance for each case. Calculate the force of air resistance for each trial (the weight of the filters).

4) To determine the relationship between the force of air resistance and velocity of the objects we are going to plot a graph of Force vs velocity.

This graph should not yield a straight line, therefore there is not a direct relationship between the force of air resistance and the velocity. Your graph should reveal an exponential relationship between force velocity.

Attach your graph to this lab.

Questions: (answer in complete sentences)
1) Draw a free body diagram for the air filter as it fell the last 2 meters.

2) As the coffee filter fell, from rest, describe what happened to the force of air resistance acting on the filter.

3) (a) As the coffee filter fell, from rest, what happened to its velocity until it reached terminal velocity?

   (b) During the same interval of time, what happened to the acceleration of the coffee filter?

4) Sketch a velocity vs. time graph and a displacement vs time graph of the coffee filter as it fell from rest to the floor.
Air Resistance (Modified)

**Purpose:**
Determine the mathematical relationship between the force of air resistance acting on a moving object and the object’s velocity.

**Introduction:**
In this lab you will look at the effects of air resistance on paper coffee filters. Since these filters of a mass of only **0.9 grams**, air resistance has a noticeable effect. At the instant the filter is dropped, its initial velocity is zero and the only force acting on it is its weight. As the filter increases in speed, the force of air resistance on the filter also increases. Eventually, the force of air resistance exactly equals the weight of the filter. This is called equilibrium. At this point the net force acting on an object is zero ($\sum F = 0$). According to Newton’s first law of motion, when the net force acting on an object is equal to zero, the object will be either at rest or moving at a constant velocity. This velocity is referred to as the object’s terminal velocity.

If you change the weight of the filter, the terminal velocity will be reached when the force of air resistance equals this new weight. By changing the weight of the filter you can observe the relationship between the force of air resistance and the velocity of the object.

**Materials:**
Stopwatch, Meter sticks and Coffee Filters

**Procedure:**
1. Determine the average time of fall for each number of filters.
2. Since you may assume the filters are falling at a constant velocity (terminal velocity) over the 1.5 meters, you can calculate their average speed. Determine the terminal velocity for each trial.
3. Since the force of air resistance and the weight of the filters are equal if the object is falling at a terminal velocity, we can calculate the force of air resistance for each case. Calculate the force of air resistance for each trial (the weight of the filters).
4. To determine the relationship between the force of air resistance and velocity of the objects, we are going to plot a graph of Force (y axis) vs. Velocity (x axis).
5. Another way to help determine the relationship between two variables is to attempt to create a direct relationship by manipulating the variables. This can be done by plotting a graph of Force (y axis) vs. Velocity$^2$ (x axis).
6. Complete the attached chart, graphs and questions.
Questions:
1. As the coffee filter fell, from rest, describe what happened to the force of air resistance acting on the filter.

2. As the coffee filter fell, from rest, what happened to its velocity until it reached terminal velocity?

3. If you were going to ignoring the affect of air resistance on a coffee filter, or any object in free fall, how would you describe the object’s rate of acceleration?

4. Explain what actually happens to the coffee filter’s rate of acceleration as the force of air resistance on the coffee filter continually increases?

<table>
<thead>
<tr>
<th># of Coffee Filters</th>
<th>Time</th>
<th>Average Time</th>
<th>$F_{\text{air}} = mg$</th>
<th>$v = \frac{d}{t}$</th>
<th>Velocity$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
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<tr>
<td>3</td>
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<td>4</td>
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<td>5</td>
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<tr>
<td>6</td>
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</tr>
</tbody>
</table>
5. Plot your data on the Force vs. Velocity graph. Develop an equation to represent your data and the relationship between force of air resistance acting on a moving object and the object’s velocity.

Questions Continued:
For questions 4-6 assume that the relationship you have determined for the coffee filters also holds true for cars.

6. Compared to the force of air resistance on a car traveling at 15 mph how many times greater is the force of air resistance on the same car traveling at 30 mph?
7. Compared to the force of air resistance on a car traveling at 15 mph how many times greater is the force of air resistance on the same car traveling at 45 mph?

8. Compared to the force of air resistance on a car traveling at 15 mph how many times greater is the force of air resistance on the same car traveling at 60 mph?

9. To confirm the equation you’ve developed, plot Force vs. Velocity$^2$ on the graph below.

10. Determine the equation of the line for the Force vs. Velocity$^2$ graph. Is it the same or different as the equation you developed from the Force vs. Velocity graph? Explain why.
Laboratory Revision Set 3

**Topic**: Centripetal Force

**The Original Lab**: “Centripetal Force Lab (Original)"

This lab also falls between the conformation level and the structured inquiry level. This is because the question, background and procedure are provided; and the results analysis and conclusion are partially provided. Much of the bold and italicized text tells the student what the results should be or what the results mean. For example, question 11 says “your graph should show an exponential relationship.” This provides the students with the conclusion about the relationship between centripetal force and speed. However, not all of the analysis and conclusions are provided in this lab.

**Rational for Change:**

The shift from the conformation level to the structured inquiry level has been made because removing the sporadically provided analysis and conclusion information is not necessary to the success of the lab. By converting this lab into a structured inquiry lab, the students are required to complete all of the analysis and develop their conclusions independently. The nature of the content lends itself well to student analysis and conclusion development. The data being collected is very reliable and with combined data of all the lab groups, the data points reveal a clear pattern that is ripe for analysis. The context of the content also supports this level of inquiry because at this point in the curriculum students have experience drawing and interrupting graphed data. While it is possible to push this lab to the guided inquiry level, the apparatus is unfamiliar to the students and would require at least a partial procedure so this lab will remain at the structured inquiry level.

**The Modified Lab**: “Centripetal Force Lab (Modified)”
This lab has been modified to be a structured inquiry lab by requiring the students to complete all of the results analysis and conclusion development independently. This improves the level of thinking required by the students and helps the students develop the targeted content knowledge. Question 9 requires the students to apply their knowledge of the newly learned content to a real world problem.
Title: Centripetal Force Lab (Original)

Problem: To determine the relationship between centripetal force and the speed of a rotating object while controlling the object’s mass and radius of orbit.

Materials: centripetal force kit
Mass set
Mass hanger
Meter stick
Stopwatch

Procedure:

1) Set up the equipment as shown in the diagram below. Be sure the rubber stopper is firmly attached to the string to prevent any unwanted mishaps.

2) Adjust the string through the tube so that the stopper will whirl in a circle with a radius of 0.5 meters. Attach a marker (piece of tape) to the string at a point just below the tube so that you can keep the radius constant.

3) Become familiar with the data table on the following page.

The centripetal force to keep the rubber stopper moving in a circle is supplied by the hanging mass.
Since the centripetal force is supplied by the tension in the string and the tension is equal to the weight of the hanging mass, calculate the centripetal force for the first trial. Show your work below.

5) Set the rubber stopper into circular motion above your head. Make sure you have your GOGGLES on.
6) With a stop watch time 10 revolutions

**Determine the period of revolution for the stopper (the time for one revolution) by dividing your time by the 10 revolutions.**

It is best to time 10 revolutions instead of 1 because you get a more accurate time per revolution by minimizing the affect of your reaction time.

7) Determine the period. Record in the data table.
8) Repeat this step 3 times and find average.
9) Repeat steps 6-8 and increase the hanging mass by 0.050 kg each trial until you have completed six trials.

<table>
<thead>
<tr>
<th>Hanging Mass</th>
<th>Centripetal Force</th>
<th>Radius</th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
<th>Average Period</th>
<th>Speed</th>
</tr>
</thead>
</table>
CALCULATING THE SPEED

Use the circumference of a circle equation to figure out how far the robber stopper moves as it travels around the circle. Show your calculation below.

We call the time it takes an object to travel one complete revolution a period.

Use the period from your data table and the distance around the circle to calculate the speed of the object as it traveled around the circle.

10) Calculate the speed at which the stopper traveled around the circle for each of your trials. Show the work for your first trial below.

11) Plot a graph of Centripetal Force vs. Speed (remember y vs. x) Your graph should show an exponential relationship.

Since the graph of centripetal force vs speed did not yield a straight line it suggests that the force is related to the speed squared. Neatly add a column to your data table and label it Speed Squared. Calculate (speed)^2 for all your trials.

12) Plot a graph of Centripetal Force vs. (Speed)^2. This graph should show a direct relationship.

Calculate the slope of your graph including units. Show your work below.
The slope of the graph equals the mass of the stopper divided by the radius of the circular path. Using your slope calculate the mass of the rubber stopper. Show your work below.

Using the digital scale, mass your rubber stopper:__________

Calculate a percent error between the actual mass and the calculated mass of the stopper. Show your work below.

Write an equation for the best fit line you drew on the Centripetal Force vs Speed\(^2\) graph. Remember to start with the equation of a line, \(y=mx+b\), substitute in appropriate variables and your slope with units.

Questions:

1) What is the relationship between the speed of an object and the centripetal force needed to keep the object moving in a circle?

1b) What do you think is the relationship between the mass of an object moving in a circular path and the centripetal force needed to keep the object moving in a circle?

1c) What do you think is the relationship between the radius of the circle and the centripetal force needed to keep the object moving in a circle? (Look at the equation you wrote, or the fact that the slope of your graph equaled the mass of the stopper divided by the radius)
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

Name_______________________  Date _________

**Centripetal Force Lab (Modified)**

**Purpose:**
Determine the relationship between centripetal force and the speed of a rotating object while controlling the object’s mass and radius of orbit.

**Materials:**
- Goggles, plastic tube, string tied to a rubber mass and several masses.

**Procedure:**
1. Set up the equipment as shown in the diagram below.

2. Adjust the string through the tube so the stopper will whirl in a circle with a radius of 0.5 m. Attach a marker (piece of tape) to the string just below the tube so you can keep the radius constant.
3. Load hanger with 100 grams of mass and set the rubber stopper into circular motion above your head. Everyone must WEAR GOGGLES.
4. With a stop watch, time 20 revolutions for each trial.
5. Answer the questions and complete the chart below.

**Questions:**
**Answer questions 1-5 when the hanger holds 150 grams of mass.**

1) Calculate the centripetal force which keeps the rubber stopper moving in a circle.
2) What is the period (time for 1 revolution)? ____________ s

3) Calculate how far an object will travel to move once around a circle with a radius of 0.5m?

4) Calculate the speed of the rubber stopper as it travels around the circle.

5) Calculate the mass of the rubber stopper.

Actual Mass______ g

6) Complete the chart below.

<table>
<thead>
<tr>
<th>Total hanging mass (kg)</th>
<th>Centripetal Force (N)</th>
<th>Radius (m)</th>
<th>Period (s)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15 kg</td>
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</tbody>
</table>

7) Share your data with other people and plot a graph of $F_c$ vs. Speed. What type of relationship does your graph show?
Conclusion:

8) Describe the relationship between centripetal force and the speed of the rotating object.

9) Apply your knowledge by answering this question. What is the fastest speed you could drive your 1100 kg car around a turn with a radius of 75m on dry asphalt?
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

**Laboratory Revision Set 4**

**Topic:** Angled Projectile Motion

**The Original Lab:** “Water Balloon Launch (Original)”

This is a structured inquiry lab because the question, background and procedure are provided but the results analysis and conclusion are not. The analysis and conclusion portions of the lab are challenging and require a solid understanding of projectile motion and the equations.

**Rational for Change:**

The shift from the structured inquiry level to the guided inquiry level has been made by removing the step by step procedure. Modifying this lab to become a guided inquiry lab was done to raise the level of thinking required by the students. In order for the students to develop their own procedure, they need to synthesize several concepts and equations from the projectile motion unit. The nature of the content lends itself well to procedure writing because the students can mathematically develop and physically test their procedural ideas. The context of the content also supports this level of inquiry because this lab comes at the end of the unit on projectile motion which means they have all of the information they need to solve the problem posed by the lab, they just need to synthesis that information into a working procedure. There are also several ways to develop a procedure that will solve the problem presented which allows for a more individualized learning process than a structured inquiry lab could offer.

**The Modified Lab:** “Water Balloon Launch (Modified)”

This lab has been modified to be a guided inquiry lab by requiring the students to develop their own procedure. This requires a high level of thinking form the students as they synthesize and test their ideas. A list of possible procedures is included at the end of the lab for the benefit of the teacher.
**Water Balloon Launch (Original)**

**Purpose:** Using the information you know about projectiles and the average launch velocity of the water balloon from your vertical projectile lab, the class is to determine what angle of launch would be necessary to strike a target at a known distance. You will not be given the target distance until the just before launch.

**Procedure:**
1. Launch the water balloon straight up into the air. Measure the flight time and divide by 2. This is the time it takes the balloon to fall from the peak to the ground.
2. Plug this time into the acceleration equation \( V_f = V_i + at^2 \) to solve for “\( V_f \)”. Keep in mind that “\( V_i \)” is the speed out of the launcher, “\( V_f \)” is 0 m/s at the peak, “\( a \)” is gravity and “\( t \)” is half the total flight time. Show your calculation below.

3. Use the value you calculated for “\( V_f \)” as the speed out of the launcher and complete the chart below. Using your reference table, show your first set of calculations for the chart’s required data.

<table>
<thead>
<tr>
<th>Angle of Launch</th>
<th>( V_x ) (m/s)</th>
<th>( V_y ) (m/s)</th>
<th>( T_{of} ) (s)</th>
<th>Range (m)</th>
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</table>
4. On Launch day you will be given your target location. Once you have this, you can complete the calculations required below.

Target Location: _____________

Angle chosen from chart: _____________

Actual Distance Traveled: _____________

Actual Time of Flight: _____________

Show the theoretical calculation for the time of flight of a water balloon launched from that angle:

Show the theoretical calculation for the range of a water balloon launched from that angle:

Calculate the percent error between the target location and the actual range of the water balloon. Show work below.

Calculate the percent error between the theoretical time of flight and the measured time of flight. Show work below.

For the chosen angle of launch calculate the maximum height reached by the projectile.
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

Questions:

1) Assuming the target was not hit, what are some reasons it didn’t work out?

2) In our calculations, we have to assume that there is no air resistance. For what angles of launch do you think the effects of air resistance will be most noticeable, and why?

3) As a general rule, as the angle of launch increases:
   The horizontal component of the velocity_____________
   The vertical component of the velocity _______________
   The range of the projectile_________________________________________________
   The maximum height reached by the projectile______________
Water Balloon Launch (Modified)

**Purpose:**
Use what you have learned about projectile motion to design a balloon launch that will hit Mr. Cali with a single shot.

**Procedure:**
On the day of the launch each group must be prepared perfectly adjust the equipment to hit Mr. Cali at any location within range. Follow the steps below to prepare for launch day.

1) Develop a step by step procedure asa group. Include three sections in your procedure. Include calculations.
   1. Set Up: Explain how to set up the equipment.
   2. Find the Launch Velocity: Explain what data will you collect and how will you use the data.
   3. Explain how to complete, and use a launch chart to select the correct angle for the given range.
   4. Explain how you will “adjust the equipment” on launch day.
2) Collect necessary data.
3) Launch Day
   - Your target is located ________ m from the launch site.
   - Select the best angle from the chart you’ve created.
   - Take your shot.

Your Written Procedure:
Questions:
1) Chart and plot data points for a “V_y vs. t_{peak}” graph of the various angles.

<table>
<thead>
<tr>
<th>V_y (m/s) y-axis</th>
<th>t_{peak} (s) x-axis</th>
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</table>

a. Calculate the slope of the graph?

b. What does the slope represent? ________________

3) Reflection:
What was the percent error between the calculated target location and the launch?

What could have improved your accuracy? What factors were uncontrollable?
<table>
<thead>
<tr>
<th>$V_y$</th>
<th>$\theta$</th>
<th>$V_{0y}=V \sin \theta$</th>
<th>$V_{0x}=V \cos \theta$</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>(m/s)</td>
<td>(m/s)</td>
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</table>
Key of Possible Procedures:

Find the velocity out of the launcher. (3 ways to do this)

a. Vertical Launch
   - Measure time of flight. Use \( V_f = V_i + at^2 \)
     - \( V_f \) = out of the launcher, \( V_i \) = at the peak, \( a \) = gravity, \( t \) = half the flight time

b. Horizontal Launch
   - Measure range. Use \( d = V_i t + \frac{1}{2}at^2 \)
     - \( t \) = flight time, \( V_i = 0 \text{ m/s} \), \( a \) = gravity, \( d \) = height above the ground
     - Then use \( V = \frac{d}{t} \)
     - \( V \) = out of the launcher, \( d \) = range, \( t \) = flight time

c. Angled Launch

Note: There is also a purely algebraic solution. This is pictured below.
Laboratory Revision Set 5

**Topic:** Impulse

**The Original Lab:** “Egg Drop (Original)”

This is a conformation lab because the question, background and procedure, results analysis and conclusion are all provided. In fact the analysis portion of the lab is extremely weak and only asks the students to complete very low level analysis of the content. For example, question 1 asks “why did you choose your design?” None of the questions on this lab required a single calculation.

**Rational for Change:**

The shift from the conformation level to the structured inquiry level has been made by requiring the students to complete a much more rigorous analysis and develop their own conclusion. This requires students to think at higher levels and develop a deeper understanding of the content. The nature of the content lends itself well to a structured inquiry lab because the impulse calculations are not dependent on the actual data. Therefore, the provided values will allow all students to achieve the same result as they analysis the information provided. The context of the content also supports this level of inquiry because this lab requires relatively simple calculations using an equation which has been taught in class. With the help of a lab partner, all of the students should be able to complete this lab successfully.

**The Modified Lab:** “Egg Drop (Modified)”

This lab has been modified to be a structured inquiry lab by requiring the students to analyze the data provided by completing the required calculations. Question 5 asks the students to draw a conclusion about the relationship between impulse, force and time. These changes made the lab better suited for the Regents physics curriculum.
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

Name___________________________ Partners________________________

EGG DROP (Original)

Purpose:

To learn about impulse by designing and building a device that will safely bring a dropped egg to rest. You can design a catching device or something cradling the egg during its fall.

Theory:

Using the equation for impulse \( F \cdot t = m(V_f - V_i) \), we can see that in order to reduce the force exerted on the egg shell, we must increase the amount of time the impulse occurs over. You will need to take this into consideration upon designing your catcher.

Materials:

You will be given a stack of plastic drinking straws, a sheet of white computer paper, 4 rubber bands, and 50 cm of tape and a paper clip. No other materials are allowed.

*The egg needs to be able to be inspected for cracks and signs of shell failure between drops.*

Scoring:

- Your score depends on the height from which the egg can be safely (no visible cracks or egg goop leaking from egg) released from
- A safe drop from 1.5 meters = 85%
- A safe drop from 2.0 meters = 90%
- A safe drop from 2.5 meters = 95%
- No safe drops = 75%
- In appropriate use of egg = 0%
- You can get +1 pt. for the best, most creative design - this is voted on by classmates
- You can get +1 pt for lightest contraption (least amount of materials used)
- You can receive up to 6 pts for answering questions 1 through 3.

You will only get 2 drops. If your egg breaks on the first try, you cannot go to a higher drop height so pick your starting height wisely.

mass of catcher and egg ______

Height of drop ______, ______
Questions:

1) Why did you choose your design? What physics principles were you trying to make use of? (use correct physics terms in your answer)

2) Are there any limits to your design? What are the design flaws?

3) Are there any changes/improvements you would make to your design?

Conclusion:

*Impulse equals the product of force and time. By building a structure to “cushion” the egg, you extended the time of impact and reduced the force on the egg.*
Egg Drop (Modified)

Purpose:
Using your understanding of momentum and impulse, build a device that will stop a falling egg without breaking it.

Materials:
- 1 egg
- 1 piece of paper
- 1 meter of masking tape
- 10 straws
- 3 rubber bands
- 1 paper clip

Drop Procedure:
All teams will make the initial drop from 1 meter. A successful drop will allow the team to drop from 0.5 meters higher than before. An egg drop is successful if the egg has no cracks or yolk leakage.

Drop Scoring:

<table>
<thead>
<tr>
<th>Height of Drop</th>
<th>1.0 m</th>
<th>1.5 m</th>
<th>2.0 m</th>
<th>2.5 m</th>
<th>3.0 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point Value</td>
<td>2/3</td>
<td>3/3</td>
<td>4/3</td>
<td>5/3</td>
<td>6/3</td>
</tr>
</tbody>
</table>

Drop Questions:
1.) What is the magnitude of the impulse required to stop an egg if it is dropped from 1m?
   a. Calculate the egg’s velocity the instant before it hits the ground.

   b. Calculate the egg’s momentum the instant before it hit the ground. (Mass of the egg = 57g)

   c. The impulse required to stop an egg falling from one meter is _________________.

2.) If the impact time is 0.005 seconds, how much force does the egg experience?

3.) How will your device change the amount and/or delivery of the impulse to prevent your egg from breaking? Explain using $J = Ft = \Delta P = \Delta mv$. 
4.) If your device was able to extend the time of impact to be 0.03 seconds how much force would the egg dropped from 1 m experience?

**Conclusion:**
5.) Describe what impulse is and how time and force were important in this experiment.

**Application Questions:**
6.) A 2100 kg car is driving at 25 m/s. How long would it take a force of 5000 N to stop the car?

7.) A free falling 0.2 kg rubber ball was traveling 5 m/s the instant before it hit the ground. After it bounces its speed is 4 m/s. If the time of impact was 0.01 s how much force did the ball experience?
Laboratory Revision Set 6

**Topic**: Projectile Motion

**The Original Lab**: “Horizontally Launched Projectiles (Original)”

This is a structured inquiry lab because the question, background and procedure are provided. While the procedure provides clear guidance through the content, the analysis is challenging. For example, question 6 asks students to “calculate how far from the base the ball will land.” This requires the synthesis of the results of two prior questions.

**Rational for Change**: The shift from structured inquiry to guided inquiry was made to promote higher levels of thinking among the students. The nature of the content is suited for guided inquiry because the equations and concepts required by the content allow students to try several approaches as they develop their procedure. The materials of the lab are also easy to work with during the development of the procedure. The context of the content also supports this level of inquiry because at this point in the curriculum, students are becoming more familiar with using equations and synthesizing concepts. Some students are even beginning to enjoy the problem solving required by a less scripted lab.

**The Modified Lab**: “Horizontally Launched Projectiles (Modified)”

This lab has been modified to be a guided inquiry lab by requiring the students to write their own procedure. Writing a procedure that accurately solves the problem, “predict were the ball will land,” requires students to have a deep understanding of the content. The analysis and conclusion of the lab are also quite challenging because they require the synthesis of several concepts.
Horizontally Launched Projectiles (Original)

**Purpose:** To predict where a projectile will land if it is launched horizontally.

**Materials:** Hot wheels track  
Meter stick  
Ball  
Stand  
Target paper

**Theory:**
As you already know, the time it takes for an object to fall to the ground only depends on how high the object is initially and the acceleration due to gravity. Therefore, an object launched horizontally from some height $x$ will land at the same time as an object dropped from that same height. We can use that fact to solve problems involving horizontally launched projectiles. If we know the velocity in the horizontal direction and the time it takes to land, we can calculate how far from the base the object lands using $v = \frac{d}{t}$.

**Procedure:**

1) Set up your hot wheels track as shown in the diagram. Be sure to set it away from the edge of the table by more than .75 meters.

2) Using a piece of tape mark a distance that is .75 meters from the edge of the table and directly in front of the track.

3) If you have a measured distance (.75m) and you measure the time it takes a marble to cross that distance you can calculate the velocity. To do this:
   a) Have one of your lab partners stand at the end of the table. Their job is to catch the ball BEFORE it lands. Failure to do this (that is, balls fall to the ground) results in a zero for the entire group on the lab!!!
   b) Have one partner release the ball from a certain height on the track. Keep in mind the higher you start, the faster the ball will be moving, and therefore the harder it is to time. You must start at the same spot every time!!!
   c) Have another person start timing when the ball crosses the tape and stop timing when the ball reaches the edge of the table. Accuracy is very important!!!

Distance Traveled: _____
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

Time: (take 20 trials)

1)____  6)____  11)____  16)____
2)____  7)____  12)____  17)____
3)____  8)____  13)____  18)____
4)____  9)____  14)____  19)____
5)____  10)____  15)____  20)____

Average Time:_____

Calculate the horizontal velocity of the ball:

4) Measure the height of the table. Again accuracy counts so be careful.

Height of table:_____

5) Calculate the time it takes an object to fall from that height.

Time:_____

6) Using the time the ball will be in the air and the horizontal velocity, calculate how far from the base the ball will land.

Distance from base:_____

7) SHOW YOUR TEACHER YOUR CALCULATIONS

8) Now that you have predicted how far it will go, it is time to test your calculations.

9) Sandwich carbon paper between the target sheets and place line at the distance away from the base of the table you calculated the ball to land. Be careful, accuracy counts.

10) Run the ball down the ramp one last time!

11) Measure how far away from the line the ball ended up.

Distance to line:_____

65
12) Calculate the percent error:

\[
\text{Percent error} = \frac{\text{distance from line}}{\text{Calculated value}} \times 100\%
\]

% error:________

IT MUST BE WITHIN 10%

Questions: (Use complete sentences)

1) What are some possible contributions to your error? In other words, what could have made your calculation wrong?

2) Why doesn’t the fact that the ball is moving horizontally have any effect on the time it takes to land?

3) Calculate the vertical velocity of the ball at the instant just before it lands?

4) What is the horizontal velocity of the ball just before it lands?

5) What is the actual velocity of the ball just before it lands?
Horizontally Launched Projectiles (Modified)
Shoot Your Grade!

Your Mission: Shoot your grade. Use your new knowledge of projectile motion to predict where the ball will land on the floor below.

Resources:
- The track and ball – You may release the ball from any location on the track.
- Photo gates – measure the time it takes the ball to travel between the gates.
- Target – determines your grade. Place it on the floor where you predict the ball will land.

Warning: You have one shot! Calculate accurately to successfully complete your mission. Only remove the projectile stopper from the end of the track when you are ready to take your shot.

Procedure: Write your own procedure below. Include the data you need to collect and a description of how you will use the data collected. Then show your calculations. Once your procedure is written and your calculations are made, you may take your shot.
Practice Problems: You may complete these before or after your shot. Completing these problems before may help you write your procedure.

1) A soccer ball is kicked horizontally off a cliff with a velocity of 20 m/s. The cliff is 100 m above ground level.
   a) How long will it take the soccer ball to hit the ground below?
   b) How far horizontally does the ball go?
   c) What is the ball’s vertical velocity as it hits the ground?

![Diagram of soccer ball trajectory]

2) An airplane moving horizontally at 150 m/s drops a package from an altitude of 490 m.
   a) How long does it take the package to hit the ground?
   b) How far forward (from where it was dropped) does the package travel?
   c) What kind of path does the package follow?

3) A boy standing on top of a hill throws a stone horizontally. The stone hits the ground 2.5 s later. From what height was the stone released?

4) Two coins are suspended off the edge of a table. One coin is shot forward horizontally, while the second coin is simply dropped vertically. Explain in sentences why both coins hit the ground at the same time.
5) An archer fires an arrow horizontally.
   a) In a sentence, describe the horizontal motion of the arrow.

   b) In a sentence, describe the vertical motion of the arrow.

c) Fill in the graphs below:

   ![Graphs of Horizontal and Vertical Motion]

   Conclusion:

   6) Using complete sentences, describe how to accurately predict where a horizontal projectile will land.
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory
Laboratory Revision Set 7

Topic: Springs

The Original Lab: “Hooke’s Law (Original)”

This lab is in-between a confirmation lab and a structured inquiry lab because some conclusions are provided in the lab. For example, question 4 says “your data should resemble a straight line” and question 6 says “your graph should intercept the y-axis at 0.”

Rational for Change:

The shift from a mixed confirmation/structured inquiry lab to a clear structured inquiry lab was made because it was not necessary to include partial conclusions throughout the original lab. Students are able to learn the content just as effectively without providing them this level of confirmation. The nature of the content is suited for a structured inquiry lab because the results of the lab are very predictable and reveal clear evidence for the validity of Hooke’s law. The context of the content also supports this level of inquiry because relatively little time is spent on Hooke’s law during class so students benefit from a clear and predictable procedure to follow that will strengthen their understanding on the content.

The Modified Lab: “Hooke’s Law (Modified)”

This lab has been modified to be a structured inquiry lab by removing the partial conclusions provided in the original lab. Students are now asked to “plot force on the spring vs. elongation” and asked to answer “what does the slope represent?” instead of being told what they should be realizing.
Name ________________________________

Hooke's Law (Original)

**Purpose:** The purpose of this lab is to determine the relationship between the elongation of an elastic material and the amount of force that the material is exerting. Force certain materials, this relationship is known as Hooke's Law.

**Equipment:**
- Hooke's Law Stand
- 2 DIFFERENT coiled springs
- small rubber band
- mass holder
- set of masses

**Procedure:** The basic procedure of this lab is to place various masses on the spring and observe the elongation of the spring.

1) Slide the scale (which is in centimeters) on the Hooke's Law stand so that the marker reads zero when there is no weight on the pan. If this is not possible due to the length of your spring, take note of the original starting value. You will have to subtract this out of every measurement.

2) Add a small amount of mass to the pan on the spring. (You may have to use a larger or smaller increment of mass for your spring).

3) Measure the amount of elongation from the apparatus.

4) Record the amount of mass (in kilograms) you placed on the spring and the amount of elongation (in meters) in a data table.

5) Repeat this procedure using appropriate increments until the elongation reaches the bottom of the scale. (Or you can no longer place masses on the pan) (AT LEAST 5 POINTS)

<table>
<thead>
<tr>
<th>Mass on Hanger (kg)</th>
<th>Stretch of Spring (m)</th>
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</table>

You now want to repeat the process with a **different spring**. Carefully replace the spring on the Hooke's Law apparatus and re-zero the scale.

6) Note on your data table which spring is “stiffer”
7) Repeat the procedure you followed for the first spring and complete the second data table.

**Spring 2:**

<table>
<thead>
<tr>
<th>Mass on Hanger (kg)</th>
<th>Stretch of Spring (m)</th>
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You now want to repeat the process with a rubber band. Carefully replace the spring on the Hooke's Law apparatus and re-zero the scale.

9) Repeat the procedure you followed for the first spring and complete the third data table.

<table>
<thead>
<tr>
<th>Mass on Hanger (kg)</th>
<th>Stretch of Rubberband (m)</th>
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**Analysis:**

1) First create a third column in each of your data tables labeled Force (N).
2) To determine the force exerted by the spring you need to know the weight of the masses you placed on the spring since the system is in equilibrium. Calculate the weight of the masses placed on your spring. Show your work below for the **first trial**.
3) Plot your results from the first spring on a graph of Force (N) as a function of Elongation (m).
4) Your data should resemble a straight line. Draw a best fit straight line through your points.
5) Determine the slope of the line you drew (show your work below). Since the values you plotted have units, your slope will also have units, in this case the units are Newtons/meter or N/m.

6) Starting with $y=mx+b$ write the equation of the best fit line below and along side the best fit line you drew. Your graphs should intercept the y-axis at 0, so your value of b should equal 0.

7) Plot the data points for the second spring on the same graph as the first spring. Draw a best fit line and determine the slope of the line with units. (Show your work below)

8) Write an equation for the line below and along the best fit line.

9) On a separate graph, plot the data points for the rubber band. The data should not yield a straight line. Draw a best fitting curve.
Questions:
1) Compare the graphs from the two springs. What does an increase in the slope physically represent for the spring?

2) How do the graphs for the springs differ from the graph of the rubber band?

3) For springs, the relationship between the elongation of the spring and the force exerted by the spring is known as Hooke’s Law and is given by the equation \( F = kx \), where \( k \) is a quantity known as the spring constant or force constant. The spring constant is a property of a given spring and is a measure of the “stiffness” of the spring. Using your graphs, determine the spring constant for each of your springs.

Spring 1

Spring 2

4) If the force exerted by an “elastic” material is directly proportional to the magnitude of the elongation of the material, the material is said to obey Hooke’s Law. Do rubber bands obey Hooke’s Law? Why did you answer the way you did?
**Hooke’s Law (Modified)**

**Purpose:**
The purpose of this lab is to determine the relationship between the elongation of a spring and the amount of force that the spring is exerting. This relationship is known as Hooke’s Law.

**Materials:**
Hooke’s Law Apparatus, 2 coiled springs, mass holder, set of masses

**Procedure:**
1. Suspend a spring form the Hooke’s law apparatus and a pan from the spring.
2. Slide the attached ruler so that the pan’s marker is at zero when there is no weight on the pan.
3. Add enough mass to the pan on the spring to observe a noticeable change in spring length.
4. Record the mass and the change in spring length (elongation) in the data table.
5. Calculate the force acting on the spring.
6. Repeat this process using various amounts of mass and without letting the pan reach the base of the apparatus

1.) Calculate the value of the force on the spring for the first trial.

2.) Collect data and fill out the chart below.

<table>
<thead>
<tr>
<th>Spring 1</th>
<th>Spring 2</th>
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<tbody>
<tr>
<td>Mass (kg)</td>
<td>Elongation (m)</td>
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<table>
<thead>
<tr>
<th>Mass (kg)</th>
<th>Elongation (m)</th>
<th>Force on the spring (N)</th>
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</thead>
<tbody>
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</table>
3.) On a single graph, plot Force on the spring (y-axis) vs. Elongation (x-axis) for both springs.
   a. Be sure to label everything properly.
   b. Draw a best fit line for each spring’s data.
   c. Which spring had a steeper slope? __________ What are the units of the slope? __________

Which spring was the strongest? __________

d. What does the slope represent?

e. Using the equation for a straight line and the variables in this lab create an equation for the
   Force on a spring (Hooke’s Law).
   \[ y = mx + b \]
   \[ y = F_s \]
   \[ x = x \text{ (change in spring length)} \]
   \[ m = k \text{ (spring constant)} \]

f. Calculate the spring constant for ....
   \[ Spring \ 1 \]
   \[ Spring \ 2 \]
4.) Using Hooke’s law, calculate the spring constant for a 10 N spring scale and a 20 N spring scale.

10 N spring scale calculations

20 N spring scale calculations

Questions:
1. The spring constant for a particular spring is $40 \text{ N/m}$. If a force of 10 N is exerted on the spring, how far will the spring stretch?

2. What force would be needed to compress a spring with spring constant equal to $20 \text{ N/m}$, 6 cm?

3. It takes 50 N of force to stretch a spring .06 meters. What is the spring constant for that spring?

4. A relaxed spring is .1 m long. A 2 kg mass is suspended from it, stretching the spring to a total length of .6 m. What is this spring’s spring constant?

5. What force would be necessary to stretch a spring from .4 m to 1 m if the spring constant is 15 N/m?
Laberaotory Revision Set 8

Topic: Waves

The Original Lab: “Wave Properties (Original)”

This lab is a confirmation lab because the question, background, procedure, analysis and conclusion are all provided to the student. It does a nice job of show students the various properties of waves but only level thinking is required.

Rational for Change:

The shift from a confirmation lab to a structured inquiry lab was made in order to require the students to be more actively engaged in the content of the lab. The original lab required very little thought from the students as they completed each step in the procedure. All they were asked to do is look for the properties described in the lab. However, the nature of the content allows for a higher level of inquiry. The slinky demonstrations used in the lab clearly represent the various wave principles being taught. This allows the students to independently analyze what they are observing and draw accurate conclusions. The context of the content also supports a structured inquiry lab because the in class demonstrations and diagrams closely resemble the lab activities. Using the slinky to make waves is intuitive for many of the students so they can easily produce and analyze the various properties of waves.

The Modified Lab: “Wave Properties (Modified)”

This lab has been modified to be a structured inquiry lab by requiring students to analyze their observations and draw their own conclusions about various wave properties. By making this shift, students are required to think more critically about what they are learning which help them develop a deeper understanding of the content.
Title: Wave Properties (Original)

Purpose: To observe the general characteristics that are common to all types of waves. That is, there are no separate characteristics for sound waves, light waves, water waves, or any other type of wave.

Materials: slinky
stop watch
Rope
A section of tape (about 1 meter long)

Procedure:

Transverse vs Longitudinal waves

1) Tape a flag onto your slinky somewhere in the middle.
2) Have your partner hold one end of the slinky while you hold the other and stretch it along the floor. Do not over stretch it...that ruins slinky's.
3) Have one person move their end of the slinky to the side and back (only once). You should have created what is called a pulse.
   a) You should see the pulse move along the same side of the slinky all the way from you to your partner.
   b) Did the particle (piece of tape) move parallel or perpendicular to the motion of the pulse?

4) Now, have one person move their end of the slinky back and forth many times one after the other. You should wave many pulses moving along the slinky now. This is called a wave train.
5) The type of wave you just created is called a transverse wave. By definition, in a transverse wave, the particles move perpendicular to the wave motion.
   a) Give some examples of other transverse waves (waves that look like the motion of the slinky)
6) Now have one person reach a short distance down the slinky’s length and gather the coils toward you then quickly release them (DO NOT LET GO OF THE SLINKY JUST THE CLUSTER OF COILS!!!!!!)

   a) The pulse travel straight through the entire slinky without moving side to side.
   b) Did the particle (piece of tape) move parallel or perpendicular to the motion of the pulse?

Note: The pulse you see traveling down the length of the slinky is called a longitudinal pulse. By definition, in a longitudinal wave, the particles move parallel to the wave motion. Sound waves are examples of longitudinal waves, so are P waves during earthquakes.

The speed of a wave is only affected by the medium it travels through.

7) Generate ONE transverse pulse in your slinky. Time how long it takes the pulse to travel the length of the slinky.

8) Keeping the stretch of the slinky constant, generate a larger or smaller amplitude transverse pulse. Time how long it takes the pulse to travel the length of the slinky.

   a) Remembering that human reaction time is about 0.1-0.2 seconds, is the speed of the two pulses approximately the same?

As the frequency increases the wavelength decreases.

9) Shake the spring back and forth RAPIDLY to generate a wave train of transverse pulses. Take note of the wavelength of the waves you created. (the wavelength is the distance from crest to crest or trough to trough)

10) Shake the spring back and forth SLOWLY to generate a wave train of transverse pulses. Take note of the wavelength of the waves you created.

   a) Compare the frequency to the wavelength of the waves you created. (Frequency of the wave is the same as the frequency at which you shook the slinky, therefore, when you shook the slinky rapidly the wave had a high frequency)
Waves combine amplitudes as they pass through each other.

11) Have your partner grasp one end of the spring while you grasp the other end. Practice sending individual pulses towards each other at the same time. Closely observe the pulses as they come together and after they pass each other (pay attention to the sizes of the pulses)

12) Now try sending pulses of equal size down the same side of the slinky at the same time.

   a) Describe what happens to the slinky where the two pulses met. Can you see the amplitudes combining as the waves pass through each other?

   b) Describe each of the pulses after they pass through each other.

13) Now try sending pulses of equal size down opposite sides of the slinky at the same time. (each person creates one pulse on opposite sides of the spring)

   a) Describe what happens to the slinky where the two pulses met. Can you see the amplitudes canceling each other out?

Reflected waves flip sides because of Newton’s 3\textsuperscript{rd} Law.

14) Have your partner hold one end of the slinky very firmly against a wall. Send a transverse pulse towards the rigid end.

   a) What happened to the pulse after it reached the wall?
The speed of a wave changes from one medium to another.

Observe as your teacher demonstrates a wave passing from one medium to another using the wave board.

a) What happens to the speed of the wave as it passes from one medium to another?

b) What happens to the wavelength of the wave as it passes from one medium to another?

c) What happens to the frequency?

Question:
15) Summarize the major characteristics of waves you have observed in this investigation. Include something from each of the sections.
Wave Properties (Modified)

Purpose:
Observe the general characteristics that are common to all types of waves.

Materials:
- Slinky, stop watch, slim slinky

Procedure and Questions:
Part 1: Transverse vs. Longitudinal Waves
- Tape a flag onto your slinky somewhere in the middle.
- Have your partner hold one end of the slinky while you hold the other and stretch it along the floor until it is about 10 meters long.
- Have one person move their end of the slinky to the side and back. You should have created what is called a pulse.
  1.) Compare the motion of the pulse to the motion of a particle (the piece of tape) in the medium (Slinky)?

- Now, have one person move their end of the slinky side to side many times. You should have many pulses moving along the slinky now. This is called a wave train or a periodic wave.
- The type of periodic wave you just created is called a transverse wave. By definition, in a transverse wave, the particles move perpendicular to the wave motion.
  2.) What are some examples of other transverse waves?

- Now have one person reach a short distance down the slinky’s length and gather the coils toward you then quickly release them without letting go of the last couple coils of the slinky. The pulse you see traveling down the length of the slinky is called a longitudinal wave.
  3.) Compare the motion of the pulse to the motion of a particle (the piece of tape) in the medium (Slinky)?
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

Part 2: Speed of a Wave
- Generate one transverse pulse in your slinky. Time how long it takes the pulse to travel the length of the slinky.
- Keeping the stretch of the slinky constant, generate a larger or smaller transverse pulse. Time how long it takes the pulse to travel the length of the slinky.

  4.) Remembering that human reaction time is about 0.2 seconds, what can you say about the speed of the various pulses?

- Now using the slim spring, generate a single transverse pulse and time how long it takes to travel the length of the slim slinky.
- Repeat for different sized pulses.

  5.) What can you say about the speed of the various pulses in the slim slinky?

  6.) What single factor affects the speed of a wave?

Part 3: Frequency and Wavelength
- Shake the spring back and forth rapidly (high frequency) to generate transverse pulses. Take note of the wavelength (distance from crest to crest) of the waves you created.
- Shake the spring back and forth slowly (low frequency) to generate transverse pulses. Take note of the wavelength of the waves you created.

  7.) Compare the frequency to the wavelength of the waves you created. What happens to the wave length as you decrease the frequency?

  8.) Does the speed of the wave change with changing frequency?
Part 4: Interference of Waves
- Have your partner grasp one end of the spring while you grasp the other end. Practice sending various pulses towards each other at the same time. Closely observe the pulses as they come together and after they pass each other (pay attention to the sizes of the pulses)
  9.) Do waves bounce off each other or pass through each other? How do you know?

- Send a pulse from each end of the slinky at the same time, on the same side, of the slinky.
  10.) What happens when the pulses meet?

- Now try sending pulses of equal size down opposite sides of the slinky at the same time.
  11.) What happens when the pulses meet?

Part 5: Reflected Waves
- Have your partner hold one end of the slinky very firmly. Send a transverse pulse towards the rigid end.
  12.) What happened to the pulse after it reached your partner? Why? (pay attention to which side the pulse is on)

Part 6: Transfer of a Wave Between Mediums
- Connect the slinky to the slim slinky by looping a few of the loops together.
- Send a pulse from the slim slinky into the regular slinky.
  13.) Describe what happens to a wave when it reaches the boundary between the two media. Describe the speed, wavelength and frequency.
Laboatory Revision Set 9

**Topic:** Light

**The Original Lab: “Reflection and Refraction (Original)”**

This lab is a confirmation lab because the question, background, procedure, analysis and conclusion are all provided to the student. For example the bold print on the last page of the lab says “the slope of your graph should represent the index of refraction of the acrylic material.”

**Rational for Change:**

The shift from a confirmation lab to a structured inquiry lab was made in order to promote higher levels of thinking as the students analyze the contents of the lab and draw their own conclusions. The original lab had every step of the procedure laid out with conclusive statements included throughout the lab. The nature of the content allows for the structured inquiry level because the concepts being taught are easily observed with the provided equipment and procedure. The context of the content also supports a structured inquiry lab because the in class demonstrations and diagrams closely resemble the lab activities. A guide inquiry lab however would not be a good fit for this context because of the basic level of observations that most first be made during this lab.

**The Modified Lab: “Reflection and Refraction(Modified)”**

This lab has been modified to be a structured inquiry lab by requiring students to analyze their observations and draw their own conclusions about the basic principles of reflection and refraction. This shift to a higher level of inquiry helps the students be a little more independent as they observe the basic principles of the content.
Name____________________________________

Title: Reflection and Refraction (Original)

When light rays are reflected from surfaces, the rays are found to be reflected in such a way that the angle of reflection is equal to the angle of incidence. This is the law of reflection. It is important to remember that both angles are measured from the normal (an imaginary line drawn perpendicular to the surface at the point of intersection), not the surface.

Purpose:
During this investigation you will
- Use the law of reflection to locate the image of an object formed by a plane mirror
- Observe the characteristics of the image

Procedure:
Part I: Images formed in a plane mirror

1) Place a sheet of paper on the cardboard. Draw line ML across the middle of the paper. Support the mirror vertically by using the plastic clip so the back of the mirror is centered on line ML.
2) Stick the pin in the cardboard through the paper about 4-5 cm in front of the mirror. Label this (P) for pin.

Look in the mirror at the image of the pin. Notice that the image appears to be behind the mirror.

3) Use the beam splitter and laser to get a long line of light across the table.
4) Aim the laser beam at the image of the pin in the mirror.
When the laser is aimed at the image of the pin, the reflected beam of light should land on the object in the same place where you pointed the laser at the image.

5) Carefully mark the direction of the incident beam with three dots. Label this A. Connect the dots and continue the line until it meets up with line ML. Label this point X.
6) Set the mirror back on the line. Move the laser to the other side of the pin. Again aim the laser at the image of the pin in the mirror.
7) Mark the direction of this beam with two dots. Label this B. Connect the dots and continue the line until it meets up with the line ML. Label this point Y.
8) Remove the pin and the mirror from the paper. Using dotted lines, extend lines AX and BY beyond the mirror line until they intersect. Label this I (the image location)
9) Measure the perpendicular distance from I to line ML. Record this information in the data table as image distance.
10) Measure the perpendicular distance from P to line ML. Record this information in the data table as object distance.
11) To show the law of reflection, draw a line from P to point X. Using your protractor construct a normal (a NORMAL is a line drawn perpendicular to the surface at the point of reflection. Label it N). Measure the angle of incidence (i) and the angle of reflection (r).
12) Draw line PY and construct a normal at Y (label it N'). Measure angles (i) and (r). Record in the data table on the next page.
Data and Observations:

<table>
<thead>
<tr>
<th>Object Distance (distance from object to mirror line)</th>
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</thead>
<tbody>
<tr>
<td>Image Distance (distance from image location to mirror line)</td>
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<tr>
<td>Angle of incidence ($\angle PXN$)</td>
<td></td>
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<tr>
<td>Angle of reflection ($\angle AXN$)</td>
<td></td>
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<tr>
<td>Angle of incidence ($\angle PYN'$)</td>
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<tr>
<td>Angle of reflection ($\angle BYN'$)</td>
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Conclusions:

*The angle of incidence always equals the angle of reflection.*

*The image of an object is located the same distance behind the mirror as the actual object is in front of the mirror.*

**Part 2: Law of Refraction**

As you know, the direction of a light ray changes abruptly when light passes across a boundary between two different media, such as between air and acrylic, or between glass and water. In this case, the change of direction is associated with the refraction of light.

A simple law characterizes this behavior of light. According to the Law of Refraction, also known and Snell’s Law:

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

The quantities \( n_1 \) and \( n_2 \) are constants, called indices of refraction, that depend on the two media through which the light is passing. The angles \( \theta_1 \) and \( \theta_2 \) are angles that the ray of light makes with the normal line.

- Set up the equipment as shown by your teacher.
- Adjust the components so a single ray of light passes directly through the center of the Ray Table. Center and Align the flat surface of the Cylindrical Lens with the line labeled “Component” as shown in Figure 1 and facing the laser.
- To check if you have everything aligned correctly, rotate the table so that the angle of incidence is 30. From the law of reflection, you know that the angle of reflection must also be 30. If the two angles are not the same, make small adjustments to the position of the lens until the angles are equal.
- By rotating the Ray Table, set the angle of incidence to each of the settings shown in the data table. For each angle of incidence, measure the angle of refraction.
- Calculate the sin of the angle of incidence and the sin of the angle of the angle of refraction.
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

Data Table: Refraction

<table>
<thead>
<tr>
<th>Angle of Incidence</th>
<th>Angle of Refraction</th>
<th>Angle of Refraction</th>
<th>Sin of Angle of Incidence</th>
<th>Sin of Angle of Refraction</th>
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<tbody>
<tr>
<td>0</td>
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On a separate sheet of graph paper, construct a graph with the sin(angle of refraction) on the x axis and the sin(angle of incidence) on the y axis. Determine the slope of the best fit line.

*The slope of your graph should represent the index of refraction of the acrylic material.*
Reflection and Refraction (Modified)

Purpose:
Observe how light can bounce and bend.

Materials:
- Plastic shape, laser, beam spreader (piece of cylindrical glass glued to a magnet), ruler and protractor, mirror, paper clip, cardboard

Procedure:
1.) Determine the index of refraction of the plastic medium.
   a. Direct the spread laser beam through the plastic medium so that it enters the medium at an angle, and leaves the plastic medium at an angle.
   b. Trace the shape of the plastic medium. Using a protractor and a ruler, draw the refracted light ray, as well as the normal lines from the two locations were the light ray is refracted.
      i. Measure and label both pairs of Incident and Refracted angles.
   c. Calculate the plastic’s index of refraction using the data collected from your picture.
   d. Record:
      | Boundary         | Angle of Incidence | Angle of Refraction | Plastic’s Calculated Index of Refraction |
      |------------------|--------------------|---------------------|----------------------------------------|
      | Into the plastic |                    |                     |                                        |
      | Into the Air     |                    |                     |                                        |
      Average Index of Refraction ____________
   e. The “plastic” medium is likely made of what material?

2.) Determine the location of a paper clip’s virtual image behind a mirror.
   a. Set the back of a mirror along center line and stand up the paper clip anywhere in the lower half of the page. From any two locations, aim a laser pointer at a single spot on the image of the paper clip in the mirror.
   b. Using a protractor and ruler, draw the actual path of the light ray from each of the laser pointer locations and the paths the image appears to take from beyond the mirror.
   c. Record:
      | Distance from the Object to the back of the Mirror |
      | Distance from the Image to the back of the Mirror |
      | Percent Error                                    |
Questions:
1.) Using Lucite’s index of refraction, calculate the speed of light in the plastic medium.

2.) As a ray of light passes into a more dense medium it will be bent __________ the normal line, its speed will __________, its wavelength will __________ and its frequency will __________

3.) The light is being refracted to an angle of 35˚ once it enters the water. Calculate the angle of incidence. A reflection is caused by a mirror at the bottom of the container. What is the angle between the incident and reflected ray?

4.) Approximately how much time does it take light to travel from the moon to the earth?

5.) What is the wavelength of a light ray with a frequency of 5.09 x 10^{14} Hz as it travels through sodium chloride?

6.) A ray of light traveling in a diamond strikes the surface of air at an angle of incidence of 20˚. What is the light rays angle of refraction into the air?

7.) Yellow light has a frequency of 5.09 x 10^{14} Hz and a wavelength of 3.07x 10^{-7} m. What material must the light be traveling through?
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

**Refraction Drawing**
Reflection Drawing
Laboratory Revision Set 10

**Topic**: Power

**The Original Lab**: “Power Lab (Original)”

This is a structured inquiry lab because the question, background and procedure are provided. This lab does a nice job of building the students’ content knowledge as they progress through the procedure and the embedded questions. The students are responsible to complete the analysis and conclusions on their own.

**Rational for Change**:

The shift from structured inquiry to guided inquiry was made to promote higher levels of thinking among the students. The nature of the content is suited for guided inquiry because the equations and concepts required by the content allow students to approach the problem in several ways. The equations are easy to manipulate and the materials of the lab can be used in multiple ways to develop an acceptable procedure. The context of the content also supports this level of inquiry. This lab happens at the end of the first semester when students are familiar with using equations and synthesizing concepts. The real life applications involved in the lab also motivates many of the students to develop procedures that answer questions they have about their exercise routines and athletic abilities.

**The Modified Lab**: “Power Lab (Modified)”

This lab has been modified to be a guided inquiry lab by requiring the students to write their own procedure. Writing a procedure that accurately solves the problem, “determine how powerful you are,” requires students to have a deep understanding of the content. There are several ways to develop the procedure that are equally valid. The relevance of the content and flexibility of the procedure writing makes this lab a good fit for a diverse group of students.
Name________________________________

Power Lab (Original)

Purpose: - To determine the power developed by yourself and your classmates.
- To determine the relationship between the rate at which work is done and the power developed.

Materials: Stopwatches, Meter sticks

Theory: The work done on an object is equal to the force times the displacement \((W=Fd)\).

Power is simply the rate at which work is done: \(P=W/t\).

Hypothesis: Predict which student in class will have the most power?

To determine your power:
1) Determine your mass in kg (record in data table)
2) Measure your displacement (height of staircase)
3) Calculate the change in your potential energy if you climb the staircase. Show your work below (assume your potential energy at the bottom of the staircase =0J). Record in the table on the next page.

4) Determine the work you need to do to against gravity to get up the stairs. Show your work below. Record in the table.

5) Time how long it takes for you to get up the stairs. Record in table
6) Calculate your power output. Show your work below. Record in table.

7) Convert your power output in watts to power output in horsepower. \((1 \text{ hp }= 746 \text{ watts})\)
Show your work below.
## Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

<table>
<thead>
<tr>
<th>Name</th>
<th>Mass (kg)</th>
<th>Height (m)</th>
<th>ΔPEg (J)</th>
<th>Work (J)</th>
<th>Time (s)</th>
<th>Power (Watts)</th>
<th>Power (hp)</th>
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</tr>
</tbody>
</table>

### Questions (answer in complete sentences):

1) Which person had the most power?

2) What factors affect a person’s power?

3) List two ways you could increase your power?
4) Assuming you could maintain the power output (rate of work) determined in this lab, calculate how much work, in Joules, you could do in the following time intervals.

<table>
<thead>
<tr>
<th>Time</th>
<th>Work (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 s</td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td></td>
</tr>
<tr>
<td>1 hour</td>
<td></td>
</tr>
</tbody>
</table>

5) If you were to jump from the top of the staircase, how much work would gravity do on you as fell to the bottom?

6) If you instead walked down the staircase, how much work would you do against gravity on the way down?
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

Name: _______________________

Physics Power Lab (Modified)

Purpose:
Determine how powerful you are.

Materials:
- Meter stick, Stopwatch, Weight Room

Helpful Information:
Work is the transfer of energy \( W = Fd = \Delta E \). The amount of work done to lift something to a certain height is equal to the amount of potential energy \( \Delta PE = mg\Delta h \) gained by the elevated object. The method or path of the lift doesn’t affect the amount of work done or the PE gained.

**Gram calorie (cal)** - approximates the energy needed to increase the temperature of 1 gram of water by 1 kelvin at standard atmospheric pressure. This is approximately 4.2 joules.

Kilogram calorie aka **Food calorie (Cal)** - approximates the energy needed to increase the temperature of 1 kilogram of water by 1 kelvin. This is approximately 4.2 kilojoules.

Conversion Factors: 1 lb. = 0.454 kg 1 hp = 746 watts 1 Cal = 4200 J

Procedure:
How will you figure out how powerful you are with the materials above? Write a procedure including the data you’ll need to collect and how you’ll use the available equations.

Experimental Details:
What exercise equipment did you use? __________________

What data did you collect? (You should have at least 3 pieces of data.)

________________________  __________________________  __________________________

________________________  __________________________  __________________________

Power Questions:
1. How powerful are you?
   a. Determine the force needed to lift the mass you selected.

Mr. Cali Approved X ____________________
b. Calculate the work done by lifting the mass you selected.

c. Calculate your power.

d. Convert your power in watts to horsepower. ______________

_Brief History: James Watt wanted a way to talk about the power of the ponies working on a coal mine. He determined that a pony could pull 330 lbs a distance of 100 ft. up a mine shaft in 1 minute, so he declared 33,000 foot-pounds of work done in 1 minute is 1 hp._

What units did James Watt use to calculate work? __________________

2. Calculate the velocity with which you must have lifted the mass you selected.

3. Assuming you could maintain the rate of work (power) you’ve calculated, how much work could you do in 5 minutes?

   a. How much energy would this require? __________________

4. How many repetitions of your work would be required to burn one dietary calorie? ____________
Practice Questions:
5. How much work required lift a 2.5 kg object to a height of 6.0 meters?

6. Eddy, who’s mass is 65.0-kg, climbs up the 1.60-meter high stairs in 1.20 s. Approximate Eddy's power rating.

7. A 51.7 kg climber ascends a vertical rope ladder 13.2-meter high at a constant speed of 0.45 m/s. Calculate the climber's power rating.

8. A flight of stairs is 3.81m (12.5 feet) tall. Mr. Cali has a mass of 86 kg. How much work is down by Mr. Cali to walk up one flight of stairs?

9. Mr. Cali just had a delicious Resee’s Peanut Butter Cup which contains 80 calories. He decides he wants to burn those calories by taking the stairs instead of the elevator. If he uses 3214 J of energy to climb one flight of stairs, how many flights of stairs would Mr. Cali have to climb to burn the 80 calories?

_________________ Flights of Stairs

Note: The tallest building in Rochester is the Xerox Tower which has 30 floors.
Laboratory Revision Set 11

**Topic:** Vectors

**The Original Lab:** “Vector Lab (Original)”

This is a structured inquiry lab because the question, background and procedure are provided. Students are required to add vectors graphically and algebraically in this lab. It’s also an active lab that allows students to move around the building and design their own vector map. The students are responsible to complete the analysis of a peers vector map and to algebraically find a vector sum.

**Rational for Change:**

The shift from structured inquiry to guided inquiry was made to promote higher levels of thinking among the students. Asking the students to write a procedure that can be used to teach their peers increases the depth of understanding that the students will achieve. The nature of the content is suited for guided inquiry because it only requires simple drawings and basic trigonometry. The context of the content also supports this level of inquiry. This lab occurs early in the year and it may be the first guided inquiry lab that some students encounter. This is a good first exposure to guided inquiry because there are virtually endless ways to write a procedure that will teach the targeted content. All of the students should be able to come up with something based on the fundamentals taught in class.

**The Modified Lab:** “Vector Lab (Modified)”

This lab has been modified to be a guided inquiry lab by requiring the students to write a procedure in question 1 that can be used by their peers in question 2 of the lab. Writing this procedure will raise the level of thinking and strengthen the student’s understanding of vectors. Although there are many ways to develop an adequate procedure, some students may struggle to
do so if this is their first exposure to a guided inquiry lab. If any of the groups’ procedures are inadequate, the teacher may choose to supply the original vector lab to any group who did not receive a procedure from their peers for question 2.
Vector Lab (Original)

Purpose:
Learn how to draw and interpret vector maps. Learn how to add concurrent vectors to calculate and measure the resultant vector.

Directions:
1. Draw all vectors Head to Tail.
2. Label each vector with a magnitude and direction.  
   5m East
3. Use a scale of 1 cm = 10 paces
4. Assume the back of the high school, where the athletic fields are, is due north.
5. Every map should include a compass rose.

Materials:
- Ruler and a protractor.

Procedure:
Prepare a map using vectors to show how to get from your starting point to your ending point.

Map #1: Mr. Cali’s Map
Starting Location = Classroom door.
Ending Location = Security Desk.

1. How many vectors did it take you? ______________

2. What was your total distance in units of paces?  Distance = __________ paces.

3. Draw a vector map in the space below by drawing all of the component vectors head to tail and then drawing the resultant vector from the start point to the end point.

4. What was your total displacement in units of paces?
   Displacement = _______ paces, ____________________________________________
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

Map #2: Design Your Own Map.
  Starting Location = Classroom door.
  Ending Location = _______________________

1. How many vectors did it take you? ______________  (must have at least 3)

2. List your vectors below. (Remember, each vector should include magnitude and direction)

2. What was your total distance in units of paces?  Distance = _______________ paces.

3. Draw a vector map in the space below by drawing all of the component vectors head to tail and then drawing the resultant vector from the start point to the end point.

4. What was your total displacement in units of paces?

  Displacement = ______ paces, _____________________________________________
Map #3: Follow Another Groups’ Map.
Starting Location = Classroom door.

Whose map are you using? _________________________________

1. Copy their list of vectors below. (Each vector should include magnitude and direction)

2. Draw a vector map in the space below by drawing all of the component vectors head to tail and then drawing the resultant vector from the start point to the end point.

3. What is the total distance in units of paces? Distance = ______________ paces.

4. What is the total displacement in units of paces?

   Displacement = ______ paces, ________________________________________________

5. Where is the End Location? _______________________


Questions:

1. Fill in the blanks with “scalar” or “vector.”

   ________________ Mass  ________________ Velocity

   ________________ Displacement  ________________ Time

   ________________ Force  ________________ Speed

2. Two forces are acting concurrently on an object. If one of the forces is 65 N and the other force is 45 N use the appropriate method for adding vectors to fill in the chart below. Show all work. Start with the 65 N force acting due east.

<table>
<thead>
<tr>
<th>Angle Between the vectors measured counterclockwise</th>
<th>Magnitude of the resultant</th>
<th>Direction of Resultant measured from due East</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38°</td>
<td></td>
<td></td>
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<tr>
<td>90°</td>
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<tr>
<td>155°</td>
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</tr>
<tr>
<td>180°</td>
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</tr>
</tbody>
</table>
Vector Lab (Modified)

Purpose:
Learn how to draw and interpret vector maps. Learn how to add concurrent vectors graphically and algebraically to find the resultant vector.

Background Information:
1. Draw all vectors Head to Tail.
2. Label each vector with a magnitude and direction.
3. Every map should include a compass rose.

Materials:
- Probable a ruler and a protractor, but you may use whatever you need.

Directions:
1. Create a lab procedure that will teach another lab group about vectors. You must include directions and questions that will help your peers understand how to add vectors graphically and algebraically. Write your procedure and questions below.
2. Once the teacher has checked your procedure and questions, you may exchange procedures with another group and complete their written procedure.
   
a. Which group did you switch procedures with? ________________________

   b. Show all of the work below that is required by the procedure you received.
Questions:
You may complete these questions at the end of the lab or while you are waiting for the teacher to check the procedures of the other lab groups.

1. Fill in the blanks with “scalar” or “vector.”

______________________ Mass  

______________________ Velocity

______________________ Displacement

______________________ Time

______________________ Force

______________________ Speed

2. Two forces are acting concurrently on an object. If one of the forces is 65 N and the other force is 45 N use the appropriate method for adding vectors to fill in the chart below. Show all work. Start with the 65 N force acting due east.

<table>
<thead>
<tr>
<th>Angle Between the vectors measured counterclockwise</th>
<th>Magnitude of the resultant</th>
<th>Direction of Resultant measured from due East</th>
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<tbody>
<tr>
<td>0°</td>
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<td>180°</td>
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</tbody>
</table>

3. Describe in your own words how to add vectors graphically and algebraically.
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

Laboratory Revision Set 12

**Topic**: Static Electricity

**The Original Lab**: “Electrostatics Fair (Original)”

This lab is a confirmation lab because the question, background, procedure, analysis and conclusion are all provided to the student. Each station contains instructions and then provides the analysis and conclusion in bold print. For example station 1 says “notice how the charged ruler didn’t fall… This is because the negatively charged ruler polarized the table’s surface…” This is a purely conformational lab.

**Rational for Change**:

The shift from a confirmation lab to a structured inquiry lab was made in order to make students more actively engaged and promote more independent critical thinking. The original lab contains a series of intriguing stations but does not require the students to do any significant analyzing or concluding. The nature of the content allows for the structured inquiry level because the phenomena being observed at each station clearly present the information need for students to independently figure out how the display is working. The context of the content also supports a structured inquiry lab because prior to the lab activity, students will have learned how charged materials interact.

**The Modified Lab**: “Electrostatics Fair (Modified)”

This lab has been modified to be a structured inquiry lab by requiring students to analyze their observations and draw their own conclusions about how charged materials interact. This shift to a higher level of inquiry helps the students think more critically and be more independent as they observe the basic principles of static electricity.
Electrostatics Fair (Original)

Purpose: Observe how charged materials interact.

Electrostatic Facts:
1. Only electrons can be transferred from one object to another or move within an object. Protons and neutrons cannot move!
2. Electrons can move within a conductor so that one side is + and the other is -. This is called a separation of charge or induced polarity.
3. Electrons do not move within an insulator.
4. Grounding an object is when you touch a charged object to the earth or provide a path for the electrons to travel to the earth. This neutralizes the object.

Materials:
1. F_e versus F_e – 2 plastic rulers, 1 fur
2. Tissue Jump – plastic ruler, fur, pieces of tissue paper
3. Tape Job - scotch tape dispenser
4. Decorate with Electrostatics - Balloon
5. Bright Idea - plastic ruler, fur, fluorescent bulb
6. Use the Force - plastic ruler, fur, meter stick, concave lens
7. Water Bending – plastic ruler, thin stream from the faucet.
   Total - 6 plastic ruler, 4 furs, 3 balloons, 1 meter stick, 1 concave lens, 1 tissue paper, string, scotch tape dispenser, fluorescent bulb, faucet.

Directions: The stations listed below are set up around the room. Go to each station and observe how charged objects interact. Be sure to read the directions and explanation at each station.

Station 1 - F_e versus F_e
Leave one ruler uncharged and hanging partly off the table. Charge the other ruler on just the half that will be resting on the table. Slide each ruler slowly until they fall off.

Notice how the charged ruler didn’t fall off even after the center point went beyond the edge table. This is because the negatively charged ruler polarized the table’s surface and clung to it, holding the ruler in place!

Station 2 - Tissue Jump
Put Electrons on the ruler by rubbing the ruler on the fur. Hold the ruler just above the tissue paper.

The tissue paper is polarized by the negatively charged ruler. This causes the positive side of the tissue paper to attract to the negative ruler.
Station 3 - Tape Job
Use two pieces of tape (Polyethylene) about the length of your thumb. Press half of each piece onto the table top letting the other half hang over the side. Rip the tape off the table. Move the free end of each piece toward each other.

*The tape pieces repeal each other because they are both negatively charged. They literally ripped electrons form the surface of the table!*

Station 4 - Decorate with Electrostatics
Rub this balloon on your head. Hold the balloon up against the ceiling above and let go.

*The rubber balloon became negatively charged by pulling electrons form your hair. Than the negatively charged balloon polarized the paint molecules on the wall and was attracted to the positive side of those molecules.*

Station 5 - Bright Idea
Build up a charge on the ruler with the fur. Move the ruler against the bottom of the fluorescent bulb.

*The bulb lights as the excess electrons on the ruler discharge into the neutral contents of the fluorescent bulb!*

Station 6 - Use the Force
The fur gives up electrons easier than the ruler. Rub the two materials together and hold the ruler near the meter stick.

*The negatively charged ruler polarizes the molecules of the meter stick. The positive side to the meter stick is then attracted to the negative ruler and begins to move.*

Station 7 - Water Bending
Build up a charge on the ruler with the fur. Hold the ruler near a thin stream from the faucet.

*The negatively charged ruler polarizes the water molecules. The positive side of the stream of mater is then attracted to the negative ruler. This cause the bend you observed in the stream of water.*

Station 8 - Completely Alike
Rub the balloons with your hair or fur. Notice how these balloons don’t hang straight down to the floor and how they move if you are near them.

*The rubber balloons were both negatively charged by pulling electrons form your hair. This causes them to repeal each other. You are neutrally charged, so the negatively charged balloons polarize your skin are attracted to the now positive surface of your skin.*
Electrostatics Fair (Modified)

Purpose: Observe and explain various electrostatic phenomena.

Electrostatic Facts:
5. Only electrons can be transferred from one object to another or move within an object. Protons and neutrons cannot move!
6. Electrons can move within a conductor so that one side is + and the other is -. This is called a separation of charge or induced polarity.
7. Electrons do not move within an insulator.
8. Grounding an object is when you touch a charged object to the earth or provide a path for the electrons to travel to the earth. This neutralizes the object.
9. The Triboelectric Series table (last page) shows which material will gain electrons when it is rubbed with another material on the chart.

Materials:
9. $F_g$ versus $F_e$ – 2 plastic rulers, 1 fur
10. Tissue Jump – plastic ruler, fur, pieces of tissue paper
11. Tape Job – scotch tape dispenser
12. Decorate with Electrostatics - Balloon
13. Bright Idea - plastic ruler, fur, fluorescent bulb
14. Use the Force - plastic ruler, fur, meter stick, concave lens
15. Water Bending – plastic ruler, thin stream from the faucet.
   Total - 6 plastic ruler, 4 furs, 3 balloons, 1 meter stick, 1 concave lens, 1 tissue paper, string, scotch tape dispenser, fluorescent bulb, faucet.

Directions: The stations listed below are set up around the room. Go to each station and try the static electricity activity. Answer the questions posed at each station while you are there.

Station 1 - $F_g$ versus $F_e$
Leave one ruler uncharged and hanging partly off the table. Charge the other ruler on just the half that will be resting on the table. Slide each ruler slowly until they fall off.

1) What happens? Why?

Station 2 - Tissue Jump
Put Electrons on the ruler by rubbing the ruler on the fur. Hold the ruler just above the tissue paper.

1) What happens? Why?
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

**Station 3 - Tape Job**
Use two pieces of tape (Polyethylene) about the length of your thumb. Press half of each piece onto the table top letting the other half hang over the side. Rip the tape off the table. Move the free end of each piece toward each other.

1) What happens? Why?

**Station 4 - Decorate with Electrostatics**
Rub this balloon on your head. Hold the balloon up against the ceiling above and let go.

1) What happens? Why?

**Station 5 - Bright Idea**
Build up a charge on the ruler with the fur. Move the ruler against the bottom of the fluorescent bulb.

1) What happens? Why?

**Station 6 - Use the Force**
The fur gives up electrons easier than the ruler. Rub the two materials together and hold the ruler near the meter stick.

1) What happens? Why?
Station 7 - Water Bending
Build up a charge on the ruler (made of PVC) with the fur. Hold the ruler near a thin stream from the faucet.

1) What’s the charge on the ruler?

2) What happens to the water? Why?

Station 8 - Completely Alike
Rub the balloons with your hair or fur. Notice how these balloons don’t hang straight down to the floor and how they move if you are near them.

1) What’s the charge on the balloons?

2) What happens? Why?

Question:
A student wearing a wool sweater over his cotton shirt can hear an electrostatic crackling sound as he pulls the sweater over his head. Use the triboelectric series table to determine the type of net charge that must be left on his cotton shirt after he has removed the sweater.

### The Triboelectric Series

<table>
<thead>
<tr>
<th>Most Positive (+)</th>
<th>Most Negative (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td></td>
</tr>
<tr>
<td>Human Hands, Skin</td>
<td>- - -</td>
</tr>
<tr>
<td>Asbestos</td>
<td></td>
</tr>
<tr>
<td>Rabbit Fur</td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td></td>
</tr>
<tr>
<td>Human Hair</td>
<td></td>
</tr>
<tr>
<td>Mica</td>
<td></td>
</tr>
<tr>
<td>Nylon</td>
<td></td>
</tr>
<tr>
<td>Wool</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td></td>
</tr>
<tr>
<td>Cat Fur</td>
<td></td>
</tr>
<tr>
<td>Silk</td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
</tr>
<tr>
<td>Paper</td>
<td></td>
</tr>
<tr>
<td>Cotton</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td></td>
</tr>
<tr>
<td>Lucite</td>
<td></td>
</tr>
<tr>
<td>Sealing Wax</td>
<td></td>
</tr>
<tr>
<td>Rubber Balloon</td>
<td></td>
</tr>
<tr>
<td>Hard Rubber</td>
<td></td>
</tr>
<tr>
<td>Nickel</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td></td>
</tr>
<tr>
<td>Silver</td>
<td></td>
</tr>
<tr>
<td>Brass</td>
<td></td>
</tr>
<tr>
<td>Synthetic Rubber</td>
<td></td>
</tr>
<tr>
<td>Gold, Platinum</td>
<td></td>
</tr>
<tr>
<td>Sulfur</td>
<td></td>
</tr>
<tr>
<td>Acetate, Rayon</td>
<td></td>
</tr>
<tr>
<td>Polyester</td>
<td></td>
</tr>
<tr>
<td>Polystyrene</td>
<td></td>
</tr>
<tr>
<td>Orlon, Acrylic</td>
<td></td>
</tr>
<tr>
<td>Cellophane Tape</td>
<td></td>
</tr>
<tr>
<td>Polynylidene chloride (Saran)</td>
<td></td>
</tr>
<tr>
<td>Polyurethane</td>
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<tr>
<td>Polyethylene</td>
<td></td>
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<tr>
<td>Polypropylene</td>
<td></td>
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<tr>
<td>Polyvinylchloride (Vinyl)</td>
<td></td>
</tr>
<tr>
<td>Kel-F (PCTFE)</td>
<td></td>
</tr>
<tr>
<td>Silicon</td>
<td></td>
</tr>
<tr>
<td>Teflon</td>
<td></td>
</tr>
<tr>
<td>Silicone Rubber</td>
<td></td>
</tr>
</tbody>
</table>

Retrieved November 1, 2014, from: [http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html](http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html)
Laboratory Revision Set 13

**Topic:** Friction

**The Original Lab:** “The Coefficient of Friction of a Shoe (Original)”

This is a structured inquiry lab because the question, background and procedure are provided. The procedure is well written and provides clear guidance through the content. The students also need to analyze their observations and data to understand information about the coefficient of friction. For example, one of the questions asks the students to graph their data and determine what the slope of that graph indicates. This requires students to understand the concept of a friction coefficient, how to calculate it and how to recognize it graphically.

**Rationale for Change:**

The shift from structured inquiry to guided inquiry was made to promote higher levels of thinking among the students. By developing their own procedure, students are forced to think critically and develop a deep understanding of the content. The nature of the content is suited for guided inquiry because the equations and concepts required by the content allow students to try several approaches as they develop their procedure. The materials of the lab are also easy to work with during the development of the procedure. The context of the content also supports this level of inquiry. Prior to the lab students will have learned about the coefficient of friction in class and seen examples of how to measure the friction force.

**The Modified Lab:** “The Coefficient of Friction of a Shoe (Modified)”

This lab has been modified to be a guided inquiry lab by requiring the students to write their own procedure. Writing a procedure that accurately solves the problem, “determine the coefficient of friction between your shoe and at least 3 different surfaces you walk on.” requires students to have a deep understanding of the content.
The Coefficient of Friction of a Shoe (Original)

Purpose:
Find out how good your shoes are at keeping you from slipping.

Objectives:
Determine the coefficient of friction between your shoe and three different surfaces.
Observe how mass and surface texture affect friction.

Procedure:
1) Measure and record the mass of your shoe.
2) Use Newton’s 2nd Law (F = ma) to calculate the Normal Force ($F_N$).
   * $a = \text{acceleration due to gravity} = 9.81 \text{ m/s}^2$
   * The force of gravity pulls the shoe and the earth together. This is why the shoe pushes down on
     the surface (weight) and so the surface pushes back with the same magnitude. The surface pushing
     back is called the Normal Force ($F_N$).
3) Attach a spring scale and pull your shoe across the clean floor at a constant rate.
4) Record the force measured by the scale to be the Force of Friction ($F_f$).
   * The force measured by the scale is actually the amount of force the shoe is putting on the surface
     in the horizontal direction to keep it moving at a constant rate. The Force of Friction ($F_f$) is equal in
     magnitude and opposite in direction so the reading on the scale is also the value of the $F_f$.
5) Use the equation $F_f = \mu F_N$ to calculate for the coefficient of friction ($\mu$) between the surfaces.
   * $\mu$ is just a known ratio the $F_f$ to the $F_N$ that is used to determine the force of friction for a given
     situation.
6) Perform the procedure above 6 times. Start with an empty shoe and add 0.3 kg to the shoe each trial.
7) Repeat steps one through six on two other surfaces made of different material.

Data and Calculations:

<table>
<thead>
<tr>
<th>Objects</th>
<th>Total Mass</th>
<th>Weight $F_N = ma$</th>
<th>Force of Friction</th>
<th>$\mu = \frac{F_f}{F_N}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sneaker</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sneaker + 0.3 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sneaker + 0.6 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sneaker + 0.9 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sneaker + 1.2 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sneaker + 1.5 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Surface:______________

1.) What is the average kinetic coefficient of friction?

$\mu = \underline{\text{ }}$

2.) Slowly increase the applied force on the shoe at rest holding 1.5 kg. What is the maximum value of the static friction force?

Static Friction = _______ N

3.) Calculate the static coefficient of friction.
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

### Surface: ________________

1.) What is the average kinetic coefficient of friction?

\[ \mu = \text{__________} \]

2.) Slowly increase the applied force on the shoe at rest holding 1.5 kg. What is the maximum value of the static friction force?

\[ \text{Static Friction} = \text{_______ N} \]

3.) Calculate the static coefficient of friction.

<table>
<thead>
<tr>
<th>Objects</th>
<th>Total Mass</th>
<th>Weight ( F_N = ma )</th>
<th>Force of Friction</th>
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<tbody>
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<tr>
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</tbody>
</table>
Graphing:
On a single graph, plot the data points for the Force of Friction (y-axis) vs. Normal Force (x-axis) of all three surfaces. Draw and label a best fit line for each surface. Be sure to label the axes and title the graph.

Calculate the slope on the graph for each surface.

What do the slopes represent? ___________________________

Which surface had the steepest slope, what does that indicate?
Questions:

1.) Draw a force diagram of the experiment while it is moving at a constant velocity. Include all of the forces acting on the shoe. (Hint: there are four force pairs which include $F_{\text{applied}}$, $F_f$, $F_g$ and $F_N$)

   $\rightarrow$ Direction of Motion $\rightarrow$

   _________________________________
   Floor

2.) Why is the force to start the shoe moving greater than the force needed to keep it moving?

3.) Your car is stuck on an ice patch and the tires are spinning. List two ways to increase the force of friction between your tires and the patch of ice.

   1) ________________________
   2) ________________________

4.) What is the force of friction on the tires of a 2000 kg car sliding at a constant speed on a dry concrete road?

5.) Use Newton’s Laws to explain the following statement.

   “Without friction between my shoes and the floor, I would not be able to walk.”

6.) A student is cross country skiing at a constant speed of 11 m/s on her freshly waxed skies. The force of friction on her skies from the snow is 32 N. What is the student’s weight?
7.) While backing out of the driveway you bump into your father’s 2000 kg car and cause it to slide backwards a little bit on the dry asphalt. After apologizing to your father you explain to him that you must have hit his car with some force greater than _______ N to have overcome the static friction force. He is so impressed he forgives you instantly. What was the maximum static friction force just before the car started to slide?

8.) A 5 kg block of copper is resting on a steel table. A force slightly greater than _______ N would be required to begin moving the block.
The Coefficient of Friction of a Shoe (Modified)

Purpose:
Find out how good your shoes are at keeping you from slipping.

Objectives:
1. Determine the coefficient of friction between your shoe and at least three different surfaces you walk on.
2. Show how mass and surface texture affect friction.

Directions:
Write a procedure below that will achieve the two objectives of this lab. You must describe the materials you will need, the data you will collect and how you will use the data to achieve the objectives. Once your procedure is approved, you may conduct your experiment.
Questions:
You may complete these at anytime during the lab. You may want to complete them while you are waiting to have your procedure approved by the teacher.

1.) Draw a force diagram of the experiment while it is moving at a constant velocity. Include all of the forces acting on the shoe. (Hint: there are four force pairs which include $F_{\text{applied}}$, $F_f$, $F_g$ and $F_N$)

   $\rightarrow$ Direction of Motion $\rightarrow$

   ______________________________________________________
   Direction of Motion
   ______________________________________________________
   Floor

2.) Why is the force to start the shoe moving greater than the force needed to keep it moving?

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Laboratory Revision Set 14

Topic: Simple Harmonic Motion

The Original Lab: “A Pendulum’s Simple Harmonic Motion (Original)”

This is a structured inquiry lab because the question, background and procedure are provided. The procedure requires the students to analyze three factors that might affect the period of a pendulum. By completing this lab, students will gain basic knowledge about simple harmonic motion.

Rationale for Change:

The shift from structured inquiry to guided inquiry was made to promote higher levels of thinking among the students. By developing their own procedure, students are forced to think critically and develop a deep understanding of the content. The nature of the content is suited for guided inquiry because the concepts required are fairly basic and can be discovered by experimentation. The materials of the lab are also easy to work with during the development of the procedure. The context of the content also supports a switch to guided inquiry because the students have some experience writing procedures from the guided inquiry labs they’ve completed in the first semester so they can draw on this experience even though this lab is their first exposure to simple harmonic and one of the first labs of the 2nd semester.

The Modified Lab: “A Pendulum’s Simple Harmonic Motion (Modified)”

This lab has been modified to be a guided inquiry lab by requiring the students to write their own procedure. Writing a procedure that accurately solves the problem, which is “what factor(s) affect the period of a pendulum?” requires students to manipulate the provided lab equipment and develop their own understanding of the content. The teacher will be monitoring and supporting the students to ensure that an accurate understanding is developed.
A Pendulum’s Simple Harmonic Motion (Original)

**Purpose:**
Determine which factors affect the period of a pendulum.

**Materials:**
- String, masses, timer, protractor, meter stick, mass hanger, ring stand

**Helpful Information:**
Period – time needed for one complete cycle
  - time for the pendulum to swing out and back to its original position

**Procedure:**
Part 1: Vary the mass.
- For each trial ...
  - Keep the length of the pendulum constant at approximately 0.7 m.
  - Keep the release angle constant at 10° from the equilibrium position.
  - Measure the time it takes to complete 5 cycles and then determine the average period.

1) Prediction: How do you think the mass of the pendulum will affect the period?

2) Collect the data and complete the chart.

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Total Mass (kg)</th>
<th>Measured Time (s)</th>
<th>Period (s)</th>
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<tbody>
<tr>
<td>1</td>
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<td>5</td>
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</table>

3) Did mass affect the period?
   a. Yes        b. No
Part 2: Vary the length.
- For each trial ...
  o Measure the time it takes to complete 5 cycles and then determine the average period.
  o Vary the length by wrapping, or unwrapping, the string around the bar it is suspended from.

1) What factor(s) will you keep constant?
____________________________________________
________________________________

2) How do you think the length of the pendulum will affect the period?

3) Collect the data and complete the chart.

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Length (m)</th>
<th>Measured Time (s)</th>
<th>Period (s)</th>
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<tbody>
<tr>
<td>1</td>
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4) Did length affect the period?
   a. Yes  b. No
Part 3: Vary the release angle.

- For each trial ...
  - Measure the time it takes to complete 5 cycles and then determine the average period.
  - Vary the release angle.

1) What factor(s) will you keep constant?
____________________________________________________________________________

2) How do you think the release angle of the pendulum will affect the period?

3) Collect the data and complete the chart.

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Release Angle (°)</th>
<th>Measured Time (s)</th>
<th>Period (s)</th>
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<tbody>
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<td>1</td>
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</table>

4) A bigger release angle means the pendulum has to swing through a bigger distance. Did this affect the period?
   - Yes
   - No

Questions:
1.) Plot graph sketches for ... (hint: Y vs. X)
   - Period vs. Mass
   - Period vs. Length
   - Period vs. Release Angle
2.) The formula for the period of a pendulum is  
   \[ T = 2\pi \sqrt{\frac{L}{g}} \]

   a. Calculate the period of the pendulum in Part 1 when it was 0.7m long.

   b. What is the average period from the data collected in Part 1? _______________

   c. Calculate the percent error between the experimental and actual values for the pendulum’s period.

3.) If you performed this lab on the moon, where  \( g = 1.6 \text{ m/s}^2 \), what would the period of a 0.7 m pendulum be?

4.) What is the frequency of a 1m long pendulum with a mass of 1kg?

5.) A rowdy crowd of Buffalo Bills fans are doing “the wave” at Ralph Wilson stadium. If Mr. and Mrs. Newton jump up once every 20s as the wave goes by, what is the frequency of “the wave?”

6.) A student stretches a rubber band between her fingers and plucks it. The rubber band then vibrates 25 times a second. Calculate the period.
7.) Draw a transverse wave below. Label the wavelength and amplitude.

8.) Draw a longitudinal wave below. Label the wavelength and amplitude.

9.) The energy transferred by a wave is directly related to what characteristic of a wave? _____________
A Pendulum’s Simple Harmonic Motion (Modified)

Problem:
What factor(s) affect the period of a pendulum?

Materials:
- String, masses, timer, protractor, meter stick, mass hanger, ring stand

Helpful Information:
Period – time needed for one complete cycle
  ○ time for the pendulum to swing out and back to its original position

Directions:
Write a procedure below that will determine what factor(s) will affect the period of a pendulum. You may use the materials provided and/or any other materials that you want. Your procedure must describe how you will use the materials you’ve selected, the data you will collect and how you will use the data to solve the problem. Once your procedure is approved, you may conduct your experiment.

Questions:

Teacher Check _______
You may answer these questions at anytime and especially while you are waiting for the teacher to approve your procedure.

1.) Test to see how the mass, length and release angle affect the period if you have not done so already. Sketch graphs of these variables below. Plot graph sketches for … (hint: Y vs. X)

   | Period vs. Mass | Period vs. Length | Period vs. Release Angle |

2.) The formula for the period of a pendulum is \( T = 2\pi \sqrt{\frac{l}{g}} \)

   a. Calculate the period of the pendulum with a 0.7m long string.

   b. Measure the actual period of a pendulum with a 0.7m long string and record it the time below.

      ______________s

   c. Calculate the percent error between the experimental and calculated (actual) values for the pendulum’s period.

3.) If you performed this lab on the moon, where \( g = 1.6 \text{ m/s}^2 \), what would the period of a 0.7 m pendulum be?

4.) What is the frequency of a 1m long pendulum with a mass of 1kg?
5.) A rowdy crowd of Buffalo Bills fans are doing “the wave” at Ralph Wilson stadium. If Mr. and Mrs. Newton jump up once every 20s as the wave goes by, what is the frequency of “the wave?”

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7.) Draw a transverse wave below. Label the wavelength and amplitude.

8.) Draw a longitudinal wave below. Label the wavelength and amplitude.

9.) The energy transferred by a wave is directly related to what characteristic of a wave? ______________
Laboratory Revision Set 15

**Topic:** Mechanics

**The Original Lab:** “Conservation of Energy (Original)”

This is a guided inquiry lab because the only the question and background are provided. The students are given a prebuilt apparatus and they must develop a procedure that will use the apparatus to show a conservation of energy. This requires higher order thinking skills and the synthesis of several concepts and equations.

**Rational for Change:**

The shift from guided inquiry to open inquiry was made to promote the highest levels of thinking among the students. Students will be given guidance on how to develop a guided inquiry lab. The only restraint will be that their lab must be based in mechanics which all of the content of the first semester. Students will need to develop a question, provided background knowledge and design a procedure that will answer their question and prove something about mechanics. Once the question, background and procedure are approved by the teacher the students may conduct the experiment. The nature of the content is suited for guided inquiry because all of the concepts and equations can be tested in many hands on ways. The context of the content also supports an open inquiry lab because the students will have recently completed the first semester, which is all about mechanics, and they have experienced many demonstrations and activities that they may be able to expand upon for this lab.

**The Modified Lab:** “Open Inquiry of Mechanics (Modified)”

This lab has been modified to be an open inquiry lab. This will require the students to think critically and creatively as they design their experiments. This will be their first experience with an open inquiry lab so they will need support from the teacher.
Conservation of Energy (Original)

Purpose:
Predict where a ball will land when released using your knowledge of potential and kinetic energy.

Materials:
- Stand, 2 crossbars, bent coat hanger, steel ball with a hole through it, meter stick and stop watches

Procedure:
1) Set up the apparatus as diagramed below.

2) Write a procedure explaining what data you will collect and what equations you will use to determine where the object will land.

Hints:
✓ To find the range of a horizontal projectile you need to know the horizontal speed and the flight time (the flight time of a horizontal projectile is the same as an object in free fall).
✓ Think about conservation of energy. What type of energy does the ball have at its highest point? What type of energy does the ball have at the bottom of the swing? How can you use this to calculate velocity?

Data:
What measurements did you take? (Ex: “Distance from the top of the swing to the bottom of the swing = 9 cm”)

Calculations:
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

Show all of your calculation for the swing.

Test Your Calculations:

Predicted Range = ________________  Actual Range = ________________

3) What was your percent error?

Questions:

1a) How would the distance out the ball went be affected if you used a different mass?

1b) How would the distance out the ball went be affected if the experiment was run in an area where the acceleration due to gravity was greater?

1c) How much work did you have to do to lift the ball up to that initial location?
2) Todd, who’s mass is 85 kg, is standing on top of a 50 meter high frictionless hill as shown below.

a) Calculate Todd’s gravitational potential energy at the top?

b) What is his potential energy at the bottom? _____________

c) What is his total mechanical energy? _____________

d) Calculate his potential energy at a point 30 meters from level ground?

e) Calculate his kinetic energy at that same point?

f) How fast is he traveling at that point?


g) How fast is he traveling at a point that is 15 meters from the ground?

h) How fast is he traveling at the bottom?

Name__________________________ Date _________

Open Inquiry of Mechanics (Modified)

Directions:
You have spent the last semester learning about Mechanics. Your challenge is to design and carry out your own lab based on something from the mechanics curriculum. You must complete each of the sections below and you may work with a partner if you want to.

**Question:**
Below, write a question that you want to answer through your experiment.

**Background:**
Provide background information that would be helpful to know prior to starting the procedure.

**Procedure:**
Write a procedure which describes the materials you will need, the steps you will take, the data you will collect and the calculations you will make to answer your question.

**Results Analysis:**
Show you collected and analyzed data here.
Conclusion:
Write about the main findings and implications of your lab.
Summary and Discussion

There are many benefits of inquiry-based instruction in science classrooms. First of all, students are thinking at higher levels by analyzing and synthesizing the content to construct their knowledge. Students are also spending more time thinking critically and creatively. They are becoming better problem solvers and learning to develop their own procedure for solving a problem. The level of student motivation also increases in inquiry-based instruction due to the autonomy and real life relevance of the learning process. Student participation increases as well because the teacher has shifted the responsibility for learning onto the students by limiting direct instruction and developing student-centered approaches to the content. These are just some of the benefits to inquiry-based instruction which compel the shift from traditional instruction to inquiry-based instruction.

The project presented in this chapter focused specifically on shifting from lower levels of inquiry in the physics laboratory to higher levels of inquiry. This was accomplished by developing a rubric which described the levels of inquiry similar to that of the rubrics presented by Nivalainen (2013) and Buck (2008). Once the rubric was developed, it was used to assess the current level of inquiry in each of the traditional physics labs that have been used in a Regents physics course. Then the content and context of each lab was considered to determine what level of inquiry would best suit the content and strengthen the students’ critical thinking skills in an efficient manner. Finally, the labs were modified to move them up to a more beneficial level of inquiry. The value of inquiry in a science course is clear, so this project was designed to better develop inquiry-based material in the Regents physics laboratory.
Shifting to Higher Levels of Inquiry in the Regents Physics Laboratory

References


