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Physics Inquiry Starters: Labs to Introduce Physics Content

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by:

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Abstract

The Next Generation Science standards emphasize students thinking and working like scientists. The New York State Board of Regents adopted the draft New York State Science Learning Standards based on the Next Generation Science Standards in December 2016 for implementation beginning July 1, 2017. Teachers are concerned about such a short timeline to implement new standards. While these standards do not include new content for Physics teachers, many of them deepen the content and require a higher level of Blooms Taxonomy to meet the standards than the previous standards. Research backs inquiry-based learning in the science classroom (Jackson & Ash, 2012; Marshall & Alston, 2014; Shemwell, Chase, & Schwartz, 2015; Banerjee, 2010). Other research has shown inquiry is effective at raising achievement scores and reducing the racial achievement gap (Corsi, 2012; Marshall & Alston, 2014; Wilson, Taylor, Kowalski, & Carlson, 2010). This project proposes using inquiry to introduce content, rather than confirm what students have already been told. This puts the students in the driver seat of learning. They will make discoveries and gain a deeper, longer-lasting connection to the material. Contained within are 22 Inquiry Starters for Physics teachers to use that introduce the content within the 17 New York State Science Learning Standards. Most of these activities will not meet the standards, but they will start the ball rolling.

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Chapter 1 - Introduction

Rationale

Science education in the United States has traditionally been teacher-centered, wherein a teacher uses direct instruction of content as the primary mode of learning. The lecture is usually followed by a laboratory activity in which the students perform a carefully orchestrated procedure designed to give the students data that reinforces the content from the lecture. The students are then assessed on the content before moving on to the next topic. This may seem like an efficient way to teach. It results in students who can recall information for their exams. However, in many cases the students do not deeply understand what they are recalling and may not even remember it after the exam.

Research has supported the use of inquiry-based learning models in the classroom as one viable way to switch to a student-centered learning experience. Studies have shown that students who learn through an inquiry-based learning model have greater achievement gains on standardized tests than those students who were taught using the traditional method described above (Jackson & Ash, 2012; Marshall & Alston, 2014; Shemwell, Chase, & Schwartz, 2015; Banerjee, 2010). Studies have also shown inquiry-based learning models are effective at closing the racial gap in achievement scores (Corsi, 2012; Marshall & Alston, 2014; Wilson, Taylor, Kowalski, & Carlson, 2010).

The National Research Council (NRC) published A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (2012) attempting to effectively increase the numbers of U.S. workers with a fundamental knowledge of science and those with a strong background in science. The NRC proposed a change from the teacher-centered classroom of old to a new student-centered classroom. One of the guiding principles of the Framework is that “children are born investigators.” The Framework led to the publication of the Next Generation Science Standards (NGSS) in 2013. The NGSS puts a great deal of emphasis on inquiry as a way for students to achieve. Many states have worked to try to incorporate these new standards. New York State Education Department released a draft version of their new standards earlier this year.

Inquiry leads to a deeper understanding of concepts and facilitates a higher level of thinking on Bloom’s Taxonomy. While traditional methods are not limited to recall (the lowest level of thinking) tasks, inquiry is better suited to scaffold thinking toward creation (the highest level of thinking) tasks. This deeper understanding can also lead to long-term retention. Wilson et al. (2010) found that students learning through inquiry retained more of the material they learned four weeks after instruction concluded than those taught by direct instruction.

While there is myriad research (Barthlow & Watson, 2014; Bybee et al, 2006; Jackson & Ash, 2012)) to support inquiry-based learning in the science classroom, there are a few large stumbling blocks to widespread implementation of inquiry in science classrooms. One issue is a large contingent of veteran science teachers who have been teaching science using the traditional method for many years. Many of these teachers are resistant to changing. Some feel as though a change like this would require them to completely rewrite their curriculum, effectively starting over as if they were in their first year of teaching. Others may avoid inquiry because they lack the content knowledge required for inquiry teaching (Sumrall, 1997). While some veterans are resistant to change, others are ready and willing to change, but they may not know how (Wilson, 2009). Many new teachers are learning about inquiry as they are training to be teachers. Many veteran teachers were not trained in this way. They must learn about inquiry through professional development, mandatory school district training programs, and collaborating with these newer teachers. For those teachers seeking to learn more about this relatively new teaching proposal that will likely be forced upon them through state mandates, there is a large body of information out there to sift through. There are many articles addressing how to incorporate inquiry into a classroom that already has an established curriculum (Bilica & Flores, 2009; Gooding & Metz, 2012; Hunter, 2014; Longo, 2011; Prince & Felder, 2007; Wilson, 2009). However, using inquiry as an introduction to content is one area where material is lacking.

This project is designed to be a collection of 22 Inquiry Starters for use with the New York State Physical Science/Physics Core Curriculum. The activities will be divided into modules that correspond with each of the three major topics within the New York State Science Learning Standards (NYSSLS) recently adopted by the New York State Board of Regents. Activities will be categorized as fitting one or more Learning Standard in the NYSSLS. Preceding each activity will be a brief description of the lab; links to research; a rationale of how the activity introduces content within the given standard and incorporates inquiry; suggested next steps in the appropriate unit; and modifications based on time and/or materials available. A lesson plan for the activity will be included. Some standards will have more than one lab. Many will have only one. Four of the standards will have no inquiry activities due to the nature of those standards. Students cannot experiment with the topics involved within a high school physics lab. The summary will reflect on the importance of the project to Physics teachers regarding the current research.

Significance of Project

The BSCS 5E Model is a popular method of incorporating inquiry into the science classroom. The 5E model emphasizes inquiry before direct instruction. Many teachers may be unsure how to incorporate inquiry before instruction. This project will aid teachers by giving them several activities that could be incorporated during the explore phase of 5E as well as suggestions for the explain phase. Some standards have multiple activities. These activities could be layered to provide the explore and elaborate phase.

Another popular inquiry model is Process-Oriented Guided Inquiry Learning (POGIL). Several of the activities included follow this model. The students are given a procedure to follow. Sometimes this is done for safety, or because the students would need to know too much information to be able to design a procedure. Guided Inquiry and POGIL are equally valid forms of inquiry, since the students do not already know the outcome and will instead inductively determine the rules governing the phenomena.

Definition of Terms

EXPOSITORY LAB: A laboratory exercise that follows choreographed steps where results are known to the teacher ahead of time. The results confirm content students already know.

HYPOTHETICO-DEDUCTIVE LAB: See EXPOSITORY LAB above.

INQUIRY-BASED TEACHING: A pedagogical method whereby students discover knowledge before being explicitly instructed.

INQUIRY LAB: A laboratory exercise that lacks either pre-choreographed steps or known outcomes. The students discover the content for themselves.

INQUIRY STARTER: An INQUIRY LAB (see above) that is done at the beginning of a domain of knowledge as an introduction to the content to come.

LAB: An activity in a science classroom wherein students are engaged in the act of doing science: making observations, collecting data, performing scientific procedures. Students are working directly with scientific phenomena, either physically or virtually.

Chapter 2 – Literature Review

Inquiry-Based Learning

Inquiry-based learning is a broad category that encompasses many methods in the science classroom. Inquiry-based learning for the purposes of this paper includes any method whereby students discover knowledge without being explicitly instructed (i.e. inductive versus deductive thinking). "Students are presented with a challenge… and accomplish the desired learning in the process of responding to that challenge" (Prince & Felder, 2007, p. 14). Whereas direct instruction is teacher-centered learning, inquiry is student-centered learning. The teacher may guide the students in the right direction, but the students explore and make discoveries. The role of the teacher is a facilitator of knowledge acquisition rather than the primary source of knowledge. The teacher's role is to design appropriate inquiry experiences.

The traditional method previously described is often referred to as the hypothetico-deductive model (Shemwell, et al., 2015). The basis of the traditional model is that students are taught a concept, usually in a lecture atmosphere. They are then presented with a problem. The students are instructed to use what they know to form a hypothesis about what the experiment will show. These types of lab activities are easy to create since the outcomes are known and the procedures are consistent every time the lab is performed. This type of lab uses deduction since the students use logic to confirm or refute their hypothesis from data gathered. The students start with the outcome and work backwards. Inquiry works in the opposite direction. Students using inquiry will analyze data that is either provided or collected during a laboratory activity, to make inferences about the laws governing the observed phenomenon. Students infer the content based on their own observations and data gathered. For example, in a traditional physics class, students are taught the constant acceleration due to gravity on Earth (g) and then complete a lab activity where the students gather data that confirms the notes they took. Conversely, in an inquiry-based physics class, students might develop an experiment to test the rate of acceleration of multiple objects dropped from the same height or a single object dropped from different heights. Students could then determine that all objects fall at the same rate on Earth and see that the force of gravity is affected only by an object's mass (F=mg). Inquiry is more closely related to how early scientists like Isaac Newton discovered the Law of Universal Gravitation (McMaster & Oxley, 2005). Hypothetico-deductive learning requires someone to know the outcome of the experiment, whereas inquiry is how brand new discoveries can be made. Inquiry is an essential process of doing science (NRC, 2012).

Process-Oriented Guided Inquiry Learning. One popular method of inquiry is Process-Oriented Guided Inquiry Learning (POGIL). According to Barthlow and Watson (2014), POGIL works on the basis that students who are actively engaged in the learning process understand complex concepts to a deeper level than those students who remain passive in the learning process—such as with the teacher-centered, lecture-dominant traditional pedagogy. POGIL also emphasizes collaboration among students. A typical POGIL lesson may begin with a short introductory lecture of no more than ten minutes. Students then meet with their groups to discuss the topic introduced in the brief lecture. After a prescribed period for that lesson, the teacher calls the students' attention to the whole class. Each group gives a report of what they have learned or discovered regarding the POGIL activity. Groups then return to their work on the activity. The teacher circulates among the groups to help only when requested. The lesson concludes with the groups sharing what they've learned with the rest of the class. While the teacher guides the lesson by supplying a short background at the beginning and guided questions to steer the inquiry, the students are responsible for what they learn. More information and resources can be found at pogil.org.

The BSCS 5E Model. One of the most commonly recognized methods for inquiry is the BSCS 5E Instructional Model. In 2006, Rodger Bybee and colleagues compiled a lengthy report of the history and effectiveness of the 5E Instructional Model (5E). 5E was developed in 1987 as part of the BSCS *Science for Life and Living* curriculum development. Bybee et al. discuss the evolution of instructional models from the early 1900s through the mid-1980s on which 5E is based. They then support the validity of the 5E by citing many supportive studies.

5E states direct instruction alone is not sufficient for students to successfully learn content. On the other hand, pure inquiry is time-consuming and therefore, nearly impossible to fit into the constraints of a normal secondary science class. Bybee and colleagues admit that neither method is inherently bad. The issue becomes when one method is solely utilized to the detriment of the other. The 5E model integrates a bit of each into a single model. The 5E model is comprised of five phases of learning: Engage, Explore, Explain, Elaborate, and Evaluate.

The Engage phase is designed to hook the students into the content to be learned. This is the opportunity for the teacher to present the problem and establish the rules and procedures for the task. Engagement should create a disequilibrium in students surrounding the topic. “Successful engagement results in students being puzzled by, and actively motivated in, the learning activity” (Bybee, et al., 2006, p. 9).

The Explore phase allows a great deal of inquiry. Exploration is a natural, psychological need in children and adolescents because of engagement. During this phase, the students can explore the topic at hand, to gain experience and create a relationship with patterns and variables. The first part of the inquiry process is for students to gather their data about the topic. The teacher initiates the activity, but the students are free to explore the phenomenon based on his/her own ideas. “Exploration is the act of searching for information” (Hunter, 2014, p. 381).

Now that students have some first-hand experience with the phenomenon, the teacher may point to specific aspects of the previous phases and ask students for their explanations to the phenomenon. Oftentimes, the teacher will then incorporate direct instruction to clarify the scientific or technological explanations for the phenomenon based on the students’ own experiences and explanations. This is also the time to introduce vocabulary pertinent to the concept. This phase is designed to be brief, concise, and address alternate conceptions (Contant, Bass, & Carin, 2014).

With the scientific, or technological explanations and vocabulary in mind, students then progress to the Elaborate phase. Here they will explore more deeply the phenomenon at hand. Bybee refers to Audrey Champagne (1987) for a clear description for this phase: “students engage in discussions and information-seeking activities. The group’s goal is to identify and execute a small number of promising approaches to the task” (p. 82). In other words, this phase allows students to work collaboratively with their classmates to learn about the phenomenon more deeply and apply what they learned in the previous phases. This phase can also introduce students to new situations that may require transfer of similar or identical explanations. A deeper understanding of the concepts, processes, and skills is the primary goal of this phase.

The final phase is assessment of educational outcomes. The Evaluation phase can be an exercise wherein the students self-assess what they have learned, but they must receive feedback on the adequacy of their understanding. If the topic being studied is a step in a scaffolded lesson plan, this phase can inform the next lesson.

Inquiry is Important for All Learners

Research has shown inquiry-based learning to be more effective than direct instruction at not only raising achievement, but also closing the gender, race, and socio-economic status (SES) achievement gaps in science education. Inquiry is also effective in acquisition of deeper understanding and retention of knowledge. Learning through inquiry leads to greater levels of engagement. Higher engagement has been directly linked with higher achievement.

Raising Achievement. Barthlow and Watson (2014) conducted a study of secondary chemistry students from four large suburban high schools to determine the effectiveness of using POGIL to reduce alternate conceptions related to the particulate nature of matter. Of the four schools, High School A (HSA) was determined to be demographically similar to High School B (HSB), as was High School C (HSC) with High School D (HSD). The control group for this study consisted of the chemistry classes from one of each pair of schools that were instructed using the traditional teacher-centered, lecture-dominant pedagogy. The experimental group consisted of the chemistry classes from the other school in each pair that were taught using POGIL methods and materials supplied by the study authors. The results showed students taught using POGIL performed 14.8% higher on standardized tests than those taught using the traditional pedagogy—14.8% higher equates to roughly an entire letter grade.

Wilson et al. (2010) conducted a study of 58 student volunteers to examine the effectiveness of the BSCS 5E Model against traditional pedagogy. The 58 students were drawn from 24 schools in seven school districts across a range of urban, suburban, and rural areas. Five of the students attended private school, while two were home-schooled. The students were divided into two groups for this study. The first group was taught the lesson—National Institutes of Health (NIH) Curriculum Supplement Series: *Sleep, Sleep Disorders,* and *Biological*

Rhythms—using traditional pedagogy methods emphasizing learning terms and facts, introducing content through formal presentations, and students watching demonstrations. The experimental group was taught to the same learning goals by the same teacher as the first group; however, the second group was taught utilizing the 5E model. The gender, race, age, and (SES) were not significantly different between the two groups. This unit was chosen for several reasons: it fell outside of the standard curriculum and was, therefore, not likely to be familiar to any of the students; the length of the unit fit within the two-week constraints of the study; and the unit was already formulated using the BSCS 5E Model.

The results of this study indicate that students who were taught utilizing 5E reached increased the margin between pre- and post-test scores significantly more than those students who experienced the traditional pedagogy. The effectiveness of the inquiry-based 5E teaching was consistent across the different learning goals of the unit.

Dr. Gianluca Corsi (2012) conducted a study of 76 eighteen-year old students over a two-year period in five Environmental Science classes at a large high school in the suburbs of Dallas, Texas, to determine if there was any statistical difference in the achievement of "at-risk" students performing inquiry-based labs as compared to those completing expository labs. The students in this study were all labeled as at-risk academically by the Texas Education Agency due in part to their low SES and Special Education Status. During the two years of the study, students completed 50 labs. Five labs were chosen as examples of the expository lab. Expository labs "provide systematic approaches to test the problems and answer the research questions" (p. 45), much like the hypothetico-deductive labs discussed previously. Another five labs allowed students to research and experiment on their own, using the principles of inquiry. Data was collected from two cohorts over the two years of study. This study showed at-risk students who performed inquiry labs scored higher on post-tests, as well as reported more science confidence than the students who completed the traditional expository labs.

Marshall and Alston (2014) published the results of a five-year study looking at the effects of a professional development (PD) titled *Inquiry in Motion*. The purpose of the PD was to help teachers move to a more inquiry-based instruction model. The participants in the study included 74 teachers and 9,981 students, from 11 schools in five districts. The focus was on schools with ethnically diverse populations. The results showed teachers who adopted the inquiry-based model in their classrooms saw increasing rates of proficiency on the Measure of Academic Progress (MAP) science test. This adaptive test provides students with future questions based on how well they answer previous questions; therefore, it encompasses more of the curriculum than a standard fixed-form test.

Inquiry-based learning models consistently raise achievement scores on standardized tests. Studies that compare the standardized test scores of students learning the traditional pedagogy of direct instruction to those learning through inquiry methods, such as 5E, overwhelmingly show the benefits of inquiry. Different studies employed different types of standardized tests. Regardless of the type of test employed, the inquiry methods garnered higher scores and greater improvement over time than did direct instruction.

Closing Achievement Gaps in Race, Gender, & Socio-economic Status. One of the driving forces behind *A Framework* and *NGSS* is the widening gap in achievement scores by race, gender, and SES. While achievement scores have increased in some areas, researchers are noticing a lower increase in minority students and those of lower SES. Many studies have specifically looked at whether inquiry could be effective at closing these achievement gaps.

Marshall and Alston (2014) found that not only did the rates of proficiency increase because of the professional development (PD) designed to add more inquiry into the science classroom, but they saw a narrowing of the racial achievement gap compared to Caucasians. This is an important aspect of the inquiry-based PD initiative. Racial minorities historically score lower on science standardized tests than their Caucasian classmates. This study shows that by switching to inquiry-based learning, those achievement gaps may be reduced, while also raising the achievement of the Caucasian students.

Wilson, et al. (2010) also found inquiry effective at closing the achievement gaps by gender, race and SES. Other studies, such as Barthlow and Watson (2014) found overall increases in student achievement, but no statistical difference by race, gender, or SES. However, the primary goal of Barthlow’s and Watson’s study was not whether inquiry closes achievement gaps, but whether it raises overall achievement.

Jackson and Ash (2012) implemented an inquiry-based PD plan at two Texas elementary schools in the hopes of improving science achievement. These two schools saw a dramatic increase in the percentage of students rated as proficient on the Texas Assessment of Knowledge and Skills (TAKS). The increase surpassed district average gains. The TAKS results also showed a decreasing race and SES gap over the three-year study.

A review of the available literature show inquiry is effective at raising overall achievement scores on standardized tests while simultaneously closing the race, gender, and SES gaps. That claim cannot be made for traditional pedagogy.

Deeper Understanding & Retention. Direct instruction does not necessarily attach meaning to the content. Therefore, some students do not gain a deep understanding of the content. Students take notes and memorize what they wrote to be recalled during the test. Once the test is over, many of the students forget some of what they learned. Studies have shown that inquiry not only leads to a deeper understanding of the concept, but also long-term retention of that knowledge.

Wilson et al. (2010) also conducted a standardized, open-ended interview with the students four weeks after they completed the NIH unit on sleep and sleep disorders. The interview was based on the topics of sleep behavior, circadian rhythms, and the biological clock—all topics discussed during the two-week unit. Students were presented with visual data on sleep patterns they had not previously seen, then guided through constructing explanations for the patterns based on the data and what they knew about the topics at hand. They were asked to construct alternate explanations, as well as respond to the validity of given explanations for the patterns. Finally, students were assessed on the knowledge they gained four weeks earlier at a higher level than just simple recall. The results showed the achievement gains were consistent four weeks later. The students who learned the 5E lessons maintained their achievement gains over time, whereas the students learning under the traditional methods fared worse after time had elapsed.

Peker & Wallace (2011) examined the lab reports of 16 secondary biology students in the southeastern United States. They discovered that most student explanations came from first-hand experiences in the laboratories and not from theories presented through direct instruction. While this study did not specifically focus on inquiry, it is important to look at how students synthesize knowledge. The knowledge they used to write their lab reports came from what they discovered through inquiry and not the knowledge that was taught through direct instruction.

Per these studies, inquiry does lead to a deeper understanding and longer retention than direct instruction. Students who can discover the principles behind a phenomenon will understand better than those who are simply told how the phenomenon works.

Driving Engagement & Increasing Attitudes Toward Science. Inquiry can also drive engagement in the sciences. Engagement is often the hook that gets students to want to be active participants in learning. 5E puts engagement right out front as the first step toward inquiry. Interested students are more likely to explore more deeply and thereby learn more deeply. Jackson & Ash (2012) found elementary students taught science through inquiry methods became so engaged in science they did not want to stop learning science. The students began to see science everywhere.

Longo (2011) looked at two middle school science classrooms. One teacher used the traditional “cookbook lab” (p. 7) while the other used an inquiry lab. There was little statistical difference in the learning outcomes between the two classes; however, the students that performed the inquiry labs were more motivated, and many were still interested in the topic a week later. The students who did cookbook labs complained about having to write a lab reports and were reportedly glad when the labs were complete. Introducing inquiry may have also sparked the desire in some of those students to pursue a science-related field.

Incorporating Inquiry into the Science Classroom

As previously stated, there are several issues with widespread incorporation of inquiry into the science classroom. These issues are not insurmountable, however. There are resources available to anyone willing to put in the time to find them. Many articles have been published over the years specifically targeting how to incorporate inquiry into a classroom with an established curriculum in place.

Inquiry in the Science Classroom. In the introduction, inquiry was defined as any method whereby students discover knowledge without being explicitly instructed. Inquiry is student-centered learning. Inquiry is at the center of science culture. “Introducing children to the culture of science—its types of reasoning, tools of observation and measurement, and standards of evidence, as well as the values and beliefs underlying the production of scientific knowledge—is a major instructional challenge” (Donovan & Bransford, 2005, p.421).

Bilica & Flores (2009) propose meeting this challenge through the Thinking Lesson Model. This model is made up of two different paths, each using the same five basic steps. The Inductive Thinking Lesson Model begins with examples and non-examples of a phenomenon. Students then brainstorm characteristics based on their observations. The next step is to organize those characteristics. In step four, students hypothesize a concept and finally write a learning statement. The other path, The Deductive Thinking Lesson Model, switches steps one and four, so that students start with an introduced concept and work toward finding examples and non-examples (see **Figure 1**). This juxtaposition of inductive and deductive thinking steps can be applied to established deductive curricula. Starting with examples and non-examples and inviting students to work toward the concept will introduce inquiry into a previously hypothetico-deductive lesson.

Gooding & Metz (2012) agree with Bilica and Flores. Many cookbook labs can be easily converted to inquiry labs by rearranging the steps of the lesson. The content often means more once the students have the experience in the lab. There are some warnings given by the authors. Not all content lends itself to inquiry. The physics class that determined that all objects fall at the same rate on Earth would not easily be able to extrapolate the Theory of Universal Gravity. That concept is difficult to model effectively on Earth. Another caveat is student safety. Not every activity can be safely left to inquiry without content being delivered first. Electricity can be a dangerous topic if students do not understand the risks first. Material shortages may also be a concern because many schools are governed by strict materials budgets. In cases of safety concerns for students or material shortages, it is permissible to perform the experiment as a demonstration for the students and then ask them to extrapolate the concept from the data you have given them. Gooding and Metz include a very concise graphic showing the various level of inquiry and who performs each step of the lab process. In the desired level of inquiry (see Figure 2), the teacher poses a problem and the students are responsible for planning a procedure to use, carrying out the procedure, supplying answers or conclusions, and then using the outcomes to drive further learning.

Longo (2011) offers advice on how to create inquiry labs. Providing students with a rubric (see Figure 3) allows students to know what it is expected of them. Asking students to collaborate with classmates allows the teacher to listen to the ideas being circulated and aid as needed. Asking students to submit a rough draft of their proposed procedures can help mitigate any safety issue. The teacher can read through the proposed procedures before they are performed. If there are no safety issues, students then perform their procedure and collect data. They then use that data to draw conclusions. Finally, students write up their lab report and submit it for evaluation. Longo suggests extending the inquiry even further through writing a blog or presenting the findings in an oral report.

Prince & Felder (2007) discuss a few methods of inquiry. Discovery learning is like the types previously discussed. Students are presented with a challenge and gain the required knowledge by addressing that challenge. Problem-based learning starts with an open-ended, real-world problem. Students must properly define the problem and brainstorm the best solution for it. They then defend their solution. When students identify areas where they need further instruction, the teacher can either instruct directly or guide the students to learn it on their own. Project-based learning (and the hybrid problem/project-based learning) requires students to create something. The hybrid form is more common and grounded much more in inquiry. True project-based learning is typically the application of previous knowledge to create a product; however, using a project as the culmination of a problem-based lesson can be beneficial.

Prince and Felder introduce two other methods of inquiry: case-based teaching and just-in-time teaching (JiTT). Through case-based teaching, students analyze historical or hypothetical cases and extrapolate information. Students are asked to work alone or in small groups. JiTT asks the students to respond to conceptual questions electronically before each class. The teacher would then be able to adapt the lessons to respond to alternate conceptions. Each of these methods require different levels of planning and resources. There are also differing levels of student resistance to these methods. The authors supply a table showing each method, the resources required, the level of planning and instructor involvement, and level of student resistance (see Figure 4).

For those teachers looking to create new inquiry-based activities, Wilson (2009) suggests starting with the textbook. Textbooks are a large content resource that can both give teachers ideas for inquiry, as well as provide any background knowledge on the topic the teacher may be missing. The trick to starting with the textbook is to not try to incorporate everything in the text. Once a teacher has chosen an appropriate topic, the next step is to define the specific objectives of the activity. Clearly defining the learning objectives will help in developing the procedures that follow. Once the activity is created, it is advisable to divide the students into small groups of two or three for the activity. Collaboration is a large part of inquiry. It is also helpful to give each student a copy of the directions, rubrics, handouts, etc. Asking all students to read the instructions carefully will allow the teacher to answer any unforeseen questions to the large group once, rather than repeating the answers to each group. It will also provide an opportunity to demonstrate any procedures that may be confusing, or pose a safety concern.

Remsburg, Harris, and Batzli (2014) looked at incorporating direct instruction of process skills before inquiry. They found that students with the necessary process skills could perform much deeper inquiry. However, Tang, Coffey, Elby, and Levin (2010) caution not to try to teach students a particular method of inquiry. They found that instructing ninth grade students on the traditional scientific method resulted in students who were more concerned that their inquiry was following the prescribed steps than the inquiry itself. Process skills such as how to use the equipment and how to calculate certain values is imperative to a productive inquiry, but a roadmap of how to get there takes the inquiry and makes it deductive.

There are many ways to incorporate inquiry into the science classroom. There are numerous resources for teachers who want to transform their “cookbook labs” into inquiry labs as well as resources for creating brand new inquiry labs. There are also numerous methods to choose from. Students will likely be engaged by a variety of methods.

Doing Science. NRC published the *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* to improve science education in the United States. They did not feel that science education was meeting its goals, including, but not limited to “providing students with engaging opportunities to experience how science is actually done” (p. 1). A strong emphasis of the *Framework* is to get students doing science.

The emphasis on doing science was carried on a year later with the publication of *Next Generation Science Standards* (NGSS). Over half of the states collaborated and took the

Framework and created a set of science standards for K-12 that were not only developmentally appropriate, but also scaffold from kindergarten through high school graduation. The NGSS includes performance expectations in each domain for each grade level, as well as science and engineering practices, and crosscutting concepts. Most of the performance expectations included in NGSS involve students doing science. For example, high school physical science standard HS-PS2-5 states: “Students who demonstrate understanding can plan and conduct an investigation to provide evidence that an electrical current can produce a magnetic field and that a changing magnetic field can produce an electrical current” (p. 253). Other standards ask students to use models to demonstrate understanding. Planning and investigating and using models to illustrate a concept are core behaviors of scientists making new discoveries while working in the field.

Doing science is not just limited to conducting experiments and analyzing the data to learn something new. Scientists also analyze data that others have collected and procedures that others have proposed. Doing science involves thinking like a scientist and behaving like a scientist. Inquiry gets right to the core of doing science.

Implications & Summary

Inquiry-based learning has been shown to be more effective at raising standardized achievement rates than the traditional science pedagogy of direct instruction, deductive labs, and summative assessment. There are many methods of inquiry-based learning, and they all facilitate a deeper understanding of the content. Inquiry not only raises overall achievement scores, it has been shown to reduce the race, gender, and SES gaps. Engagement in science has been identified as a critical factor to improving the science education of American students. Inquiry is effective at increasing not only engagement, but also attitudes towards science and science-related fields.

A Framework for K-12 Science Education and the NGSS have begun the push toward incorporating inquiry into the science classrooms in every state. Some states have already begun adapting NGSS into their current standards. The New York State Education Department (NYSED) released a draft of its version of the NGSS for feedback from educators in early 2016. Few changes were made to the original NGSS by NYSED. Some domains saw the addition of performance standards and core ideas. The new standards will be mandated by NYSED and the departments of education in other states. It is no longer a question of *if* they will be mandated, but *when* will they be mandated. Teachers are in a unique position to begin to adapt their teaching to the new standards before they are forced to. The same opportunity was not afforded with the rollout of Common Core State Standards earlier this decade. Now is the time to incorporate inquiry and begin to practice what may be a new method of instruction. For the teachers using inquiry in the classroom, it would be wise to use this time to ensure the new standards are covered.

Teachers wishing to incorporate inquiry now would do best to remember that students learning through an inquiry model may need more feedback on their progress than they did under the traditional pedagogy. In the more student-centered atmosphere, teachers must be willing to give up complete control and students will need to adjust to the autonomy that comes with inquiry. Parsons, Miles, and Petersen (2011) surveyed 844 students from a mid-sized, urban school district about what types of teaching strategies they think help them learn best. Most students think they learn better through passive strategies rather than active ones. This survey is important to keep in mind when incorporating inquiry in the classroom. The perception of students is that passive is better for learning, even though studies show the opposite. Students may be resistant to these changes. It would be important to focus on a single activity to add inquiry rather than trying to change everything at once. One of the great things about inquiry is that it doesn't have to be absolute. There are degrees of inquiry ranging from teacher-directed to teacher-guided to completely open. Beginning with a single inquiry activity will introduce the students to the concepts behind shifting the responsibility to them. "The strength of the inquiry lab is in the shift of accountability and work from the teacher to the student" (Corsi, 2012, p. 50).

The BSCS 5E Model places much emphasis on student exploration before direct instruction. This follows all the research. 5E advocates for a hook-inquiry-direct instruction-deeper inquiry-assessment cycle. This method of inquiry is time-tested and well received by many educators.

This body of research supports the notion that incorporating inquiry in the curriculum will increase not only student achievement, but also students' attitudes toward science and science-related fields. Beginning with inquiry lab activities can greatly improve motivation and accelerate advancement to higher levels of thinking. Allowing students to discover science before being instructed can lead to more students pursuing science-related fields. Providing young people with a strong background in science is the purpose of science education. Inquiry as an introduction to content is a research-based method to accomplish that very task.

Chapter 3 – Capstone Project

Module 1: Forces and Interactions

This module contains the five standards within the *Forces and Interactions* section of the NYSSLS.

- HS-PS2-1 deals with Newton's Second Law of Motion. There is one activity included for this standard.
- HS-PS2-2 deals with conservation of momentum. There are four activities included that can be used individually or in conjunction with one another.
- HS-PS2-3 is an engineering extension to HS-PS2-2. There are no new activities included.
- HS-PS2-4 deals with Newton's Law of Gravity and Coulomb's Law. There is one activity for each Law.
- HS-PS2-5 deals electromagnetic induction. There is one activity included.

Standard HS-PS2-1.

“Analyze data to support the claim that Newton’s Second Law of Motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. [Clarification Statement: Examples of data could include tables, graphs, or diagrams (vector diagrams) for objects subject to a net unbalanced force (a falling object, an object sliding down a ramp, an object being acted on by friction, a moving object being pulled by a constant force, projectile motion, or an object moving in a circular motion), for objects in equilibrium (Newton’s First Law), or for forces describing the interaction between two objects (Newton’s Third Law).][Assessment Boundary: Assessment is limited to macroscopic objects moving at non-relativistic speeds whose measured quantities can be classified as either vector or scalar.]” (NYSSLS, 2016, p. 55).

Newton’s Second Law. This activity is based on AP Physics 1 Investigation 2: Newton’s Second Law (The College Board, 2015, p. 61-75).

Activity description. “In this lab students investigate how the acceleration of an object is related to its mass and the force exerted on the object, and use their experimental results to derive the mathematical form of Newton’s second law. Students should have already completed the study of kinematics and Newton’s first law” (The College Board, 2015, p. 61).

Students will first design a procedure to calculate the acceleration of a system with a constant mass and a changing applied force. The second design will incorporate a system with a changing mass and constant applied force.

Activity rationale. This investigation will expose students to the principles of Newton’s Second Law of Motion. Students will be presented with guiding questions to answer through student-designed investigations. Students may need guidance in designing a proper apparatus and procedure. This lab could be very difficult for some students. This topic is typically early in the year. Guided inquiry is acceptable. However, before this activity is attempted, students should have a firm understanding of kinematics and Newton's first law of motion.

Activity modifications. If this is one of the first inquiry starters of the year, teachers may want to begin with a demonstration setup. "A modified Atwood's machine with a system consisting of a cart and a hanger with slotted masses like the one shown in Figure 5 is a suitable setup" (The College Board, 2016, p. 66). Teachers also may want to demonstrate how the apparatus works and then ask students to describe what they are observing. Then allow them to use the apparatus in a guided inquiry where the students figure out the appropriate procedure to answer the guiding questions.

Suggested next steps. Through this investigation, students will get first-hand experience with how the applied force or the mass affects acceleration of a system. Some students may derive Newton's Second Law equation based on their data. This would be an appropriate time to introduce Newton's Second Law Equation a=F/m.

Lesson Plan:

<table>
<tr><td>Central Focus for the learning segment:
Newton’s Second Law of Motion</td></tr>
<tr><td>Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].)
NYSSLS 2016 – HS-PS2-1:
Analyze data to support the claim that Newton’s Second Law of Motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. [Clarification Statement: Examples of data could include tables, graphs, or diagrams (vector diagrams) for objects subject to a net unbalanced force (a falling object, an object sliding down a ramp, an object being acted on by friction, a moving object being pulled by a constant force, projectile motion, or an object moving in a circular motion), for objects in equilibrium (Newton’s First Law), or for forces describing the interaction between two objects (Newton’s Third Law).][Assessment Boundary: Assessment is limited to macroscopic objects moving at non-relativistic speeds whose measured quantities can be classified as either vector or scalar.]</td></tr>
<tr><td>Learning Objectives associated with the content standards:
Students will be able to describe the effects on a system’s acceleration when changing the mass of the system
Students will be able to describe the effects on a system’s acceleration when changing the force applied to the system</td></tr>
<tr><td>Instructional Resources and Materials to engage students in learning:
“Per lab group (three to four students):
Dynamics track
Cart
Assorted masses
Mass hanger and slotted masses
Low-friction pulley
String
Meter stick
Stopwatch
If you do not have a dynamics track, then any at, smooth surface, perhaps even the lab tables themselves, will work just ne. The carts should have wheels with a small rotational-inertia and low-friction bearings.

Data acquisition using motion detectors or photogates is recommended when available, as it helps reduce experimental procedural errors. Another option is to record a video of the motion of the cart and use video analysis software to analyze the motion.” (The College Board, 2015, p. 64)</td></tr>
</table>

Language Function students will develop. Additional language demands and language supports: • Force • Mass • Acceleration
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their proposed procedure to answer the guiding questions. • Formal Assessment: Students will be formally assessed on how well they follow their proposed procedure and how they choose to analyze the data collected.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.
Lesson Timeline: A. Students are presented with the guiding questions and a list of available materials (2-3 min.) 1. What happens to the acceleration of a system with a constant mass if the applied force is varied? 2. What happens to the acceleration of a system with a varying mass if the applied force is constant? B. Students design an experiment to gather data to answer the guiding questions and make predictions for the outcome (5-7 min.) C. Each group shares their design with the class. (5-10 min.) 1. At least one group should share their predictions for the outcome. 2. Students should give and receive feedback on experiment design from their peers. D. Students perform their experiments and collect data. (15-20 min.) E. Students analyze their data to come up with general rules for both situations. (5-10 min.) F. Students share the general rules they have written based on their collected data. (5-10 min.)

Standard HS-PS2-2.

“Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.]” (NYSSLS, 2016, p. 55).

Momentum. This activity is based on AP Physics 1 Investigation 5: Impulse and Momentum (The College Board, 2015, p 107-121).

Activity description. This short activity is designed to give students “a qualitative introduction to the concept of momentum and how objects interact when they collide” (The College Board, 2016, p. 113). Students will qualitatively compare the stopping force needed for two identical carts traveling at different speed and two carts of different mass traveling at the same speed. Students will then be asked to come with a way to demonstrate the stopping force needed. Suggestions include a spring or a ball of clay. Students will then be asked to explain what they see (e.g., what is the significance of the dent in the clay or the compression of the spring).

Activity rationale. This activity will give students a qualitative understanding of momentum. Much of this activity follows the POGIL structure. Students are given a procedure to follow. However, the last part of the lab allows students to design their own simple stopping mechanism. Through this inquiry activity, students will begin to understand the concept of momentum.

Activity modifications. This activity could be done as demonstration if there are not enough carts and tracks for each group of students. Also, the lab tables could be used as the track, if your school does not own enough, or any, tracks. To launch the cars toward each other, it is recommended that the students build a rubber band slingshot; however, any method of launching the cars is acceptable, since this activity is intended to be qualitative.

Suggested next steps. Now that students have an experience with momentum, this would be an appropriate time to introduce them to the momentum equation: $p=mv$. Some students may have already determined that there is an inverse relationship between mass and velocity.

Lesson Plan.

Central Focus for the learning segment: • Momentum
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS2-2: Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.]
Learning Objectives associated with the content standards: • Students will be able to describe the difference in stopping force needed for two identical carts of differing speeds and for two cars of differing masses traveling at the same speed. • Students will be able to design a simple stopping mechanism that will qualitatively show the stopping force needed.
Instructional Resources and Materials to engage students in learning: "Per lab group (three to five students): • Two spring-loaded carts • Track • Bubble level • Known calibrated masses (three to four per station, in the range of 200–500 g) and at least two objects with unknown mass (also in the range of 200–500 g) • Calculator • Meter stick • Stopwatch • Computer with Internet access • (Optional) Video camera and analysis software • (Optional) Force sensor • (Optional) Motion sensor with calculator or computer interface" (The College Board, 2015, p. 111)
Language Function students will develop. Additional language demands and language supports: • Mass • Velocity • Momentum • Impulse

Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their adherence to the procedure. • Formal Assessment: Students will be formally assessed on how well they explain the difference in stopping forces for each scenario and their design of the simple stopping mechanism.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.
Lesson Timeline: A. Students are presented with the POGIL directions to read through (2-3 min.) B. Students follow the procedures (13-17 min.) 1. Move two identical carts toward each other on the track at differing speeds. 2. Try to stop both carts at the same time using your hands. 3. Which cart required more stopping force? Why? 4. Move two carts of differing masses toward each other on the track at the same speed. 5. Which cart required more stopping force? Why? 6. Design a simple stopping mechanism that will demonstrate the stopping force needed. 7. Explain how the stopping force will be demonstrated by your mechanism. 8. Ask the teacher to approve your mechanism. C. Each group shares their results and mechanism with the class. (5-10 min.) D. Students come up with a general rule for the relationship between mass and speed. (5-10 min.)

Colliding Carts. This activity is based on AP Physics 1 Investigation 5: Impulse and Momentum (The College Board, 2015, p 107-121).

Activity description. "In this activity students design an experiment in which two carts gently collide with each other in different ways" (The College Board, 2016, p. 114). The students should design a procedure to measure the velocity of the carts before and after different types of collisions. It is recommended that students examine at least four variations of collisions. Students must measure the mass and velocity of both carts before and after the collisions. Using that data, students should calculate the momentum of the system before and after the collisions.

Activity rationale. This activity will show students the effects of different types of collisions. This will also show them that momentum is conserved. Since the students will be designing the procedures to gather data about different types of collisions, this activity is guided inquiry.

Activity modifications. This activity could be done as demonstration if there are not enough carts and tracks for each group of students. Also, the lab tables could be used as the track, if your school does not own enough, or any, tracks. To launch the cars toward each other, it is recommended that the students build a rubber band slingshot; however, any method of launching the cars is acceptable.

Suggested next steps. This would be an appropriate time to introduce the concept of conservation of momentum. Many of the students may have already reasoned that momentum is conserved, based on their data.

Lesson Plan.

Central Focus for the learning segment: • Conservation of Momentum
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS2-2: Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.]
Learning Objectives associated with the content standards: • Students will be able to describe effects of different types of collisions on momentum. • Students will be able to show that momentum is conserved after an elastic collision.
Instructional Resources and Materials to engage students in learning: “Per lab group (three to five students): • Two spring-loaded carts • Track • Bubble level • Known calibrated masses (three to four per station, in the range of 200–500 g) and at least two objects with unknown mass (also in the range of 200–500 g) • Calculator • Meter stick • Stopwatch • Computer with Internet access • (Optional) Video camera and analysis software • (Optional) Force sensor • (Optional) Motion sensor with calculator or computer interface” (The College Board, 2015, p. 111)
Language Function students will develop. Additional language demands and language supports: • Mass • Velocity • Momentum • Impulse • Conservation
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their proposed procedure. • Formal Assessment: Students will be formally assessed on how well they perform their proposed procedures and gather the appropriate data.

Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:
A. Students are presented with the guiding question and a list of available materials (2-3 min.)
    1. What is the momentum before and after different types of collisions?
B. Students design an experiment to gather data to answer the guiding question and make predictions for the outcome (5-7 min.)
C. Each group shares their design with the class. (5-10 min.)
    1. At least one group should share their predictions for the outcome.
    2. Students should give and receive feedback on experiment design from their peers.
D. Students perform their experiments and collect data. (15-20 min.)
E. Students analyze their data to come up with a general rule for each type of collision. (5-10 min.)
F. Students share the general rules they have written based on their collected data. (5-10 min.)

Explosions. This activity is based on AP Physics 1 Investigation 5: Impulse and Momentum (The College Board, 2015, p 107-121).

Activity description. "In this activity, students build up to the idea of conservation of momentum via 'explosions' of two objects moving away from one another. This can be done with two identical carts with a spring compressed between them. Releasing the spring will cause the carts to move apart, and students then calculate the momentum of both carts. Prior to releasing the carts, have the students predict what they expect to happen when the carts are released. They should come up with the expectation that if the carts start at rest, the final total momentum of the two carts should be zero. Then have students extend the activity to carts of unequal mass to again show that total momentum is constant" (The College Board, 2016, p. 11).

Activity rationale. This will show the students that momentum is conserved. Since the students will be designing the procedures to gather data about different types of explosions, this activity is guided inquiry.

Activity modifications. This activity could be done as demonstration if there are not enough carts and tracks for each group of students. Also, the lab tables could be used as the track, if your school does not own enough, or any, tracks.

Suggested next steps. This would be an appropriate time to introduce the concept of conservation of momentum. Many of the students may have already reasoned that momentum is conserved, based on their data.

Lesson Plan.

Central Focus for the learning segment: • Conservation of Momentum
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS2-2: Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.]
Learning Objectives associated with the content standards: • Students will be able to describe the effects of an elastic collision by examining the actions after the collision. • Students will be able to show that momentum is conserved after an elastic collision.
Instructional Resources and Materials to engage students in learning: “Per lab group (three to five students): • Two spring-loaded carts • Track • Bubble level • Known calibrated masses (three to four per station, in the range of 200–500 g) and at least two objects with unknown mass (also in the range of 200–500 g) • Calculator • Meter stick • Stopwatch • Computer with Internet access • (Optional) Video camera and analysis software • (Optional) Force sensor • (Optional) Motion sensor with calculator or computer interface” (The College Board, 2015, p. 111)
Language Function students will develop. Additional language demands and language supports: • Mass • Velocity • Momentum • Impulse • Conservation • Explosion

Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their proposed procedures. • Formal Assessment: Students will be formally assessed on how well they perform their proposed procedures and collect appropriate data.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.
Lesson Timeline: A. Students are presented with the guiding questions and a list of available materials (2-3 min.) 1. What is the momentum of two carts of equal mass as they “explode” away from each other, if both carts start at rest? 2. What is the momentum of two carts of differing masses as they “explode” away from each other, if both carts start at rest? 3. How could you ensure the velocity of one cart is exactly twice that of the other cart, if both carts start at rest? B. Students design an experiment to gather data to answer the guiding questions and make predictions for the outcome (5-7 min.) C. Each group shares their design with the class. (5-10 min.) 1. At least one group should share their predictions for the outcome. 2. Students should give and receive feedback on experiment design from their peers. D. Students perform their experiments and collect data. (15-20 min.) E. Students analyze their data to come up with a general rule for each type of explosion. (5-10 min.) F. Students share the general rules they have written based on their collected data. (5-10 min.)

Impulse and Momentum. This activity is based on AP Physics 1 Investigation 5: Impulse and Momentum (The College Board, 2015, p 107-121).

Activity description. Students will design a procedure "where they stop a moving cart with a rubber band attached to a force sensor. That would show the force/time/ impulse relationship. The cart is attached by a string/rubber band combination to a force sensor: it moves away from the sensor, extends the rubber band, stops, and then moves backward toward the force sensor. If used in conjunction with a motion detector, a full force/time/impulse/momentum analysis can be done. Several commercial types of equipment include motion sensors and force sensors that can be used for this extension. Students could produce from this data a 'Force vs. Time' graph and use the area under the graph to calculate impulse" (The College Board, 2016, p. 115).

Activity rationale. This activity will graphically show students how to calculate impulse Since the students will be designing the procedures to gather data about different types of explosions, this activity is guided inquiry.

Activity modifications. This activity could be done as demonstration if there are not motion detectors and/or force sensors for each group of students. This activity requires the use of at least a force sensor. If your school does not own any working force sensors, this activity will not be possible.

Suggested next steps. This would be an appropriate time to introduce impulse.

Lesson Plan.

Central Focus for the learning segment: • Impulse and Momentum
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS2-2: Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.]
Learning Objectives associated with the content standards: • Students will be able to describe impulse as a change in momentum. • Students will be able to show that the force of an impact is equal to the change in momentum divided by time.
Instructional Resources and Materials to engage students in learning: "Per lab group (three to five students): • Two spring-loaded carts • Track • Bubble level • Known calibrated masses (three to four per station, in the range of 200–500 g) and at least two objects with unknown mass (also in the range of 200–500 g) • Calculator • Meter stick • Stopwatch • Computer with Internet access • Force sensor • (Optional) Motion sensor with calculator or computer interface • (Optional) Video camera and analysis software" (The College Board, 2015, p. 111)
Language Function students will develop. Additional language demands and language supports: • Mass • Velocity • Momentum • Impulse
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their adherence to the procedure. • Formal Assessment: Students will be formally assessed on how well they explain the difference in stopping forces for each scenario and their design of the simple stopping mechanism.

Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:
A. Students are presented with the guiding questions and a list of available materials (2-3 min.)
    1. What is the effect on momentum when a cart is stopped and reversed using an elastic medium?
    2. How can you show graphically this change in momentum?
B. Students design an experiment to gather data to answer the guiding questions and make predictions for the outcome (5-7 min.)
C. Each group shares their design with the class. (5-10 min.)
    1. At least one group should share their predictions for the outcome.
    2. Students should give and receive feedback on experiment design from their peers.
D. Students perform their experiments and collect data. (15-20 min.)
E. Students analyze their data to come up with a general rule for an elastic medium changing momentum. (5-10 min.)
F. Students share the general rules they have written based on their collected data. (5-10 min.)

Standard HS-PS2-3.

"Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision. [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.]" (NYSSLS, 2016, p. 55).

This standard is an extension of the previous standard (HS-PS2-2). Therefore, there are no additional inquiry starter activities prescribed for this standard. Utilizing any of the four activities listed under standard HS-PS2-2 will suffice.

Standard HS-PS2-4.

"Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.] [Assessment Boundary: Assessment is limited to systems with two objects.]" (NYSSLS, 2016, p. 55).

Charged Balloons.

Activity description. In this activity, students will charge two balloons with roughly equal static charge. They will then slowly bring the balloons close together. The balloons will deform as they try to repel each other. The closer they get, the more deformed they should become. Then students repeat the process with one balloon charged much more than the other. Students will record their observations of each trial. Students will gain a qualitative understanding of the electrostatic force between two charged objects.

Activity rationale. This activity will demonstrate to students the effects of electrostatic forces between two charged objects. This activity follows the guidelines of POGIL, since the procedures are set by the teacher.

Activity modifications. This activity requires very few materials, so there should be no need for any modifications

Suggested next steps. This would be an appropriate time to introduce students to Coulomb's Law: $F=kq_1q_2/r^2$.

Lesson Plan.

Central Focus for the learning segment: • Coulomb's Law
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS2-4: Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.] [Assessment Boundary: Assessment is limited to systems with two objects.]
Learning Objectives associated with the content standards: • Students will be able to qualitatively describe the effects of two charged objects as they move toward each other.
Instructional Resources and Materials to engage students in learning: Per lab group (two to four students): • Two balloons of equal volume and mass • Two patches of material suitable for charging the balloons • (Optional) Two Ring Stands • (Optional) Lengths of string to hang the balloons • (Optional) Length of string connecting the two rings stands
Language Function students will develop. Additional language demands and language supports: • Charge • Electrostatic Force
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their adherence to the procedures. • Formal Assessment: Students will be formally assessed on how they describe the effects on the balloons at roughly the same charge and differing charges, as well as the effects of distance between the balloons on the deformity.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:

A. Students are presented with the POGIL directions to read through (2-3 min.)
B. Students follow the procedures (5-10 min.)
    1. Concurrently rub both balloons with a patch of material for 1 minute.
    2. Slowly bring the two balloons close together.
    3. Make observations about the effects of the balloons as they move together.
    4. Repeat the process rubbing one balloon with the material for 30 seconds and the other for 1 minute.
    5. Make observations as the balloons move slowly toward each other.
    6. What differences do you notice between the first and second trial?
C. Each group shares their observations. (5-10 min.)
D. Students come up with a general rule for the relationship between electrostatic force, distance, and charge. (5-10 min.)

PhET Gravity Force Lab.

Activity description. In this activity, students will manipulate the masses of two objects and the distance between them to determine the effects of each on the force of gravity between them.

Activity rationale. This activity is only possible in a computer simulation. Due the massive size and close distance of the Earth, it is virtually impossible to demonstrate gravity between two objects. This activity asks students to determine the best procedures to manipulate the variables and describe their effects on the force. This is guided inquiry.

Activity modifications. This activity requires a computer station, laptop, or tablet device for every two to four students. If that is not available, this activity could be modified to a demonstration with input about what to change for the students. Or the students could take turns adjusting a variable and observing the effect it has on the force.

Suggested next steps. This would be an appropriate time to introduce students to Newton's Law of Universal Gravitation: $F=Gm_1m_2/r^2$.

Lesson Plan.

Central Focus for the learning segment: • Newton's Law of Universal Gravitation
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS2-4: Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.] [Assessment Boundary: Assessment is limited to systems with two objects.]
Learning Objectives associated with the content standards: • Students will be able to quantitatively describe the effects mass and distance on the force of gravity between two objects.
Instructional Resources and Materials to engage students in learning: Per lab group (two to four students): • Computer, laptop, or tablet with internet access.
Language Function students will develop. Additional language demands and language supports: • Gravity • Mass • Distance
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on procedures for manipulating the variables and making observations. • Formal Assessment: Students will be formally assessed on how they describe the effects mass and distance have on the force of gravity.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:

A. Students are presented with the guiding questions and web address (2-3 min.)
    1. What is the effect of mass on the force of gravity between two objects?
    2. What is the effect of distance on the force of gravity between two objects?
    3. PhET web address: https://phet.colorado.edu/en/simulation/gravity-force-lab
B. Students design an experiment to gather data to answer the guiding questions and make predictions for the outcome (5-7 min.)
C. Each group shares their design with the class. (5-10 min.)
    1. At least one group should share their predictions for the outcome.
    2. Students should give and receive feedback on experiment design from their peers.
D. Students perform their experiments and collect data. (15-20 min.)
E. Students analyze their data to come up with general rules for the effects of mass and distance on the force of gravity between two objects. (5-10 min.)
F. Students share the general rules they have written based on their collected data. (5-10 min.)

Standard HS-PS2-5.

"Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current. [Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.]" (NYSSLS, 2016, p. 55).

Electromagnetic Induction.

Activity description. "This investigation introduces the topic of electromagnetic induction and provides a solid experiential background for the discussion of magnetic flux, Faraday's law of induction, and Lenz's law. Students are asked to design experiments to determine the variables that determine the emf that can be induced in a coil by a permanent magnet" (The College Board, 2015, p. 261).

Activity rationale. "This is a guided-inquiry investigation in which students construct small coils and use a voltmeter to measure the induced emf when small neodymium magnets are moved in and through the coil. Students need to come up with a list of variables (e.g., coil size, magnet strength, speed) that may affect the emf induced in a small coil when a magnet is moved near the coil. Then they need to design and execute experiments to vary those factors and determine if and how they affect the emf generated" (The College Board, 2015, p. 262).

Activity modifications. While the materials list calls for digital multimeters, the use of analog multimeters or galvanometers is acceptable. This activity could also be done as a demonstration.

Suggested next steps. This would be an appropriate time to introduce Faraday's Law: $\mathcal{E}=-N(\Delta\Phi/\Delta t)$.

Lesson Plan.

Central Focus for the learning segment: • Electromagnetic Induction
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS2-5: Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current. [Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.]
Learning Objectives associated with the content standards: • Students will be able to describe induction of electricity due to the changing magnetic field through a coil.
Instructional Resources and Materials to engage students in learning: "Per lab group (two students): • 5–6 meters of enameled magnet wire (100 meters can be purchased online or at most electronics retail stores for less than $10) • Plastic/cardboard tube to act as a base for winding the coil of wire, such as PVC pipe or very wide drinking straw (approximately 1/2-inch inside diameter and 2 inches is long enough) • Plastic tube of larger diameter to wind a larger coil, such as a small prescription bottle (1-inch diameter and about 2 inches is long enough) • Four or more neodymium axially polarized nickel-plated disc magnets (inches) The exact number of magnets and their dimensions are not important so long as there is a sufficient quantity to separate them into at least two piles, so that the strength of each magnet group can be adjusted, and the diameters are narrow enough to be moved easily back and forth through the diameter of the smaller coil (such magnets are widely available on the web for about $0.50 each). • Digital multimeter (DMM) with a setting that will indicate to the tenths of a millivolt • Pair of connecting wires, preferably with alligator clip connectors • Electrical tape to secure leads • Sandpaper to sand off ends of coated wire • String to suspend magnets • Masking tape • Compasses • (Optional) Two eightpenny or tenpenny nails" (The College Board, 2015, p. 263-264)
Language Function students will develop. Additional language demands and language supports: • Induction • Magnetic Flux • Magnetic Field • Electromotive Force • Area Vector

Type of Student Assessments and what is being assessed:

- Informal Assessment: Students will be informally assessed on their proposed procedure to answer the guiding questions.
- Formal Assessment: Students will be formally assessed on how well they follow their proposed procedure and how they choose to analyze the data collected.

Relevant theories and/or research best practices:

- Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:

A. Students are presented with the guiding questions and a list of available materials (2-3 min.)
    1. How can you determine and label the poles of the magnet?
    2. What are the effects of a magnet moving through a coil of wire?
    3. What are the effects of the magnet moving faster or slower?

B. Students design an experiment to gather data to answer the guiding questions and make predictions for the outcome (5-7 min.)

C. Each group shares their design with the class. (5-10 min.)
    1. At least one group should share their predictions for the outcome.
    2. Students should give and receive feedback on experiment design from their peers.

D. Students perform their experiments and collect data. (15-20 min.)

E. Students analyze their data to come up with general rules a magnet moving through a coil of wire. (5-10 min.)

F. Students share the general rules they have written based on their collected data. (5-10 min.)

Module 2: Energy

This module contains the six standards within the *Energy* section of the NYSSLS.

- HS-PS3-1 deals with Conservation of Energy. There are three activities included that can be used individually or in conjunction with one another.
- HS-PS3-2 deals with conversion of energy. There is one activity included for this standard.
- HS-PS3-3 is an engineering extension to HS-PS3-2. There are no new activities included.
- HS-PS3-4 deals with the Second Law of Thermodynamics. This standard is usually covered by the Chemistry curriculum. There is one activity included.
- HS-PS3-5 deals with objects interacting in electrical and magnetic fields There is one activity included for each type of field.
- HS-PS3-6 deals with Ohm's Law. There one activity included.

Standard HS-PS3-1.

“Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions for energy, work, and power used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to work, power, thermal energy, kinetic energy, potential energy, electrical energy and/or the energies in gravitational, magnetic, or electric fields.]” (NYSSLS, 2016, p. 57).

Conservation of Energy Part I. This activity is based on AP Physics 1 Investigation 8: Mechanical Waves (The College Board, 2015, p. 159-177).

Activity description. “In this investigation, students experiment with the concept of the conservation of energy by qualitatively investigating the relationship between elastic potential energy and gravitational potential energy. Students take a spring- loaded cart and release it so that it travels up a ramp. In addition to making observations and measurements, they make predictions as to what would happen if the angle of the ramp changed. Then, students experiment quantitatively with the relationship between the compression of the spring and the gravitational potential energy of the Earth-cart system. They do this by repeating measurements of the cart on the ramp for different compressions of the spring” (The College Board, 2015, p. 89). See Figure 6 for an image of the proposed setup.

Activity rationale. This activity will introduce students to the concepts governing conservation of energy in a closed system. The students will be presented with guiding questions and be asked to design a procedure to answer the guiding question. Therefore, this activity employs guided inquiry.

Activity modifications. This activity could be done as a demonstration if there are not enough tracks and carts for each group of students. Groups could include more students, but it not recommended for groups to be any larger than 6 students.

Suggested next steps. This would be an appropriate time to introduce the concept of conservation of momentum. However, it is recommended that that students complete Conservation of Momentum Parts II and III as well. These will need to be done on successive class periods as each activity takes a whole class.

Lesson Plan.

Central Focus for the learning segment: • Conservation of Energy
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS3-1: Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions for energy, work, and power used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to work, power, thermal energy, kinetic energy, potential energy, electrical energy and/or the energies in gravitational, magnetic, or electric fields.]
Learning Objectives associated with the content standards: • Students will be able to describe the conservation of energy in a closed system, based on the conversion of one energy to other forms of energy.
Instructional Resources and Materials to engage students in learning: “Per lab group: • Low-friction dynamics cart with spring bumper (or spring-loaded plunger cart) • Ramp • Meter stick • Stopwatch • Assorted masses • Books or blocks (to create incline)” (The College Board, 2015, p. 92)
Language Function students will develop. Additional language demands and language supports: • Gravitational potential energy • Spring potential energy • Kinetic energy
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their proposed procedure to answer the guiding questions. • Formal Assessment: Students will be formally assessed on how well they follow their proposed procedure and how they choose to analyze the data collected.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:

A. Students are presented with the guiding question and a list of available materials (2-3 min.)
    1. What effects do the steepness of the ramp have on the motion of the cart if the cart starts with the spring fully compressed?

B. Students design an experiment to gather data to answer the guiding question and make predictions for the outcome (5-7 min.)

C. Each group shares their design with the class. (5-10 min.)
    1. At least one group should share their predictions for the outcome.
    2. Students should give and receive feedback on experiment design from their peers.

D. Students perform their experiments and collect data. (15-20 min.)

E. Students analyze their data to come up with a general rule for the effect of steepness on the motion of the cart. (5-10 min.)

F. Students share the general rules they have written based on their collected data. (5-10 min.)

Conservation of Energy Part II. This activity is based on AP Physics 1 Investigation 8: Mechanical Waves (The College Board, 2015, p. 159-177).

Activity description. "In this investigation, students experiment with the concept of the conservation of energy by qualitatively investigating the relationship between elastic potential energy and gravitational potential energy. Students take a spring- loaded cart and release it so that it travels up a ramp. In addition to making observations and measurements, they make predictions as to what would happen if the angle of the ramp changed. Then, students experiment quantitatively with the relationship between the compression of the spring and the gravitational potential energy of the Earth-cart system. They do this by repeating measurements of the cart on the ramp for different compressions of the spring" (The College Board, 2015, p. 89). See Figure 6 for an image of the proposed setup.

Activity rationale. This activity will introduce students to the concepts governing conservation of energy in a closed system. The students will be presented with guiding questions and be asked to design a procedure to answer the guiding question. Therefore, this activity employs guided inquiry.

Activity modifications. This activity could be done as a demonstration if there are not enough tracks and carts for each group of students. Groups could include more students, but it not recommended for groups to be any larger than 6 students.

Suggested next steps. This would be an appropriate time to introduce the concept of conservation of momentum. However, it is recommended that that students complete Conservation of Momentum Parts I and III as well. These will need to be done on successive class periods as each activity takes a whole class.

Lesson Plan.

Central Focus for the learning segment: • Conservation of Energy
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS3-1: Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions for energy, work, and power used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to work, power, thermal energy, kinetic energy, potential energy, electrical energy and/or the energies in gravitational, magnetic, or electric fields.]
Learning Objectives associated with the content standards: • Students will be able to describe the conservation of energy in a closed system, based on the conversion of one energy to other forms of energy.
Instructional Resources and Materials to engage students in learning: “Per lab group: • Low-friction dynamics cart with spring bumper (or spring-loaded plunger cart) • Ramp • Meter stick • Stopwatch • Assorted masses • Books or blocks (to create incline)” (The College Board, 2015, p. 92)
Language Function students will develop. Additional language demands and language supports: • Gravitational potential energy • Spring potential energy • Kinetic energy
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their proposed procedure to answer the guiding questions. • Formal Assessment: Students will be formally assessed on how well they follow their proposed procedure and how they choose to analyze the data collected.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:

A. Students are presented with the guiding question and a list of available materials (2-3 min.)
    1. What effect does the compression distance of the spring have on its potential energy?
    2. What effect does the elastic potential energy of the spring have on the gravitational potential energy of the cart?
B. Students design experiments to gather data to answer the guiding question and make predictions for the outcome (5-7 min.)
C. Each group shares their design with the class. (5-10 min.)
    1. At least one group should share their predictions for the outcome.
    2. Students should give and receive feedback on experiment design from their peers.
D. Students perform their experiments and collect data. (15-20 min.)
E. Students analyze their data to come up with general rules for the effect of compression distance on elastic potential energy and the relationship between elastic potential energy and gravitational potential energy. (5-10 min.)
F. Students share the general rules they have written based on their collected data. (5-10 min.)

Conservation of Energy Part III. This activity is based on AP Physics 1 Investigation 8: Mechanical Waves (The College Board, 2015, p. 159-177).

Activity description. "In this investigation, students experiment with the concept of the conservation of energy by qualitatively investigating the relationship between elastic potential energy and gravitational potential energy. Students take a spring- loaded cart and release it so that it travels up a ramp. In addition to making observations and measurements, they make predictions as to what would happen if the angle of the ramp changed. Then, students experiment quantitatively with the relationship between the compression of the spring and the gravitational potential energy of the Earth-cart system. They do this by repeating measurements of the cart on the ramp for different compressions of the spring" (The College Board, 2015, p. 89). See Figure 6 for an image of the proposed setup.

Activity rationale. This activity will introduce students to the concepts governing conservation of energy in a closed system. The students will be presented with guiding questions and be asked to design a procedure to answer the guiding question. Therefore, this activity employs guided inquiry.

Activity modifications. This activity could be done as a demonstration if there are not enough tracks and carts for each group of students. Groups could include more students, but it not recommended for groups to be any larger than 6 students.

Suggested next steps. This would be an appropriate time to introduce the concept of conservation of momentum. However, it is recommended that that students complete Conservation of Momentum Parts II and III as well. These will need to be done on successive class periods as each activity takes a whole class.

Lesson Plan.

<table>
<tr><td>Central Focus for the learning segment:
• Conservation of Energy</td></tr>
<tr><td>Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].)
NYSSLS 2016 – HS-PS3-1:
Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions for energy, work, and power used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to work, power, thermal energy, kinetic energy, potential energy, electrical energy and/or the energies in gravitational, magnetic, or electric fields.]</td></tr>
<tr><td>Learning Objectives associated with the content standards:
• Students will be able to describe the conservation of energy in a closed system, based on the conversion of one energy to other forms of energy.</td></tr>
<tr><td>Instructional Resources and Materials to engage students in learning:
“Per lab group:
• Low-friction dynamics cart with spring bumper (or spring-loaded plunger cart)
• Ramp
• Meter stick
• Stopwatch
• Assorted masses
• Books or blocks (to create incline)” (The College Board, 2015, p. 92)</td></tr>
<tr><td>Language Function students will develop. Additional language demands and language supports:
• Gravitational potential energy
• Spring potential energy
• Kinetic energy</td></tr>
<tr><td>Type of Student Assessments and what is being assessed:
• Informal Assessment: Students will be informally assessed on their proposed procedure to answer the guiding questions.
• Formal Assessment: Students will be formally assessed on how well they follow their proposed procedure and how they choose to analyze the data collected.</td></tr>
<tr><td>Relevant theories and/or research best practices:
• Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.</td></tr>
</table>

Lesson Timeline:

A. Students are presented with the guiding question and a list of available materials (2-3 min.)
   1. “What role does friction play in the experiment? How can you minimize or take into account the frictional effects?
   2. If the spring could only be compressed by two values (or if the spring could be compressed for multiple values), how would your experiment change?
   3. How does the amount of compression of the plunger change the manner in which you measure the distance the cart moved and/or the maximum height?” (The College Board, 2015, p. 96).
B. Students design an experiment to gather data to answer the guiding question and make predictions for the outcome (5-7 min.)
C. Each group shares their design with the class. (5-10 min.)
   1. At least one group should share their predictions for the outcome.
   2. Students should give and receive feedback on experiment design from their peers.
D. Students perform their experiments and collect data. (15-20 min.)
E. Students analyze their data to come up with a general rule each question. (5-10 min.)
F. Students share the general rules they have written based on their collected data. (5-10 min.)

Standard HS-PS3-2.

“Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above Earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]” (NYSSLS, 2016, p. 57).

Roller Coaster.

Activity description. During this activity, students will make a roller coaster track for a ball bearing. They will be tasked with making at least four hills. The ball bearing must be released at the top of the first hill and make it to the top the fourth hill.

Activity rationale. This activity will require students to experiment with converting gravitational potential energy into kinetic energy and back again numerous times to complete the four hills. Students will be given limited directions and will be tasked with developing a course for the ball bearing based on their knowledge. They will be allowed to change their design as they progress. This activity is a guided inquiry.

Activity modifications. This activity may be done in larger groups if there are not enough ring stands for every group. Anything that will allow the students to choose the height of each hill will also work.

Suggested next steps. This would be an appropriate time to introduce how energy conversion is part of the Conservation of Energy.

Lesson Plan.

Central Focus for the learning segment: • Conversion of Energy
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS3-2: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above Earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]
Learning Objectives associated with the content standards: • Students will be able to demonstrate their knowledge of energy conversion between gravitational potential energy and kinetic energy for the ball bearing to make it over all four hills.
Instructional Resources and Materials to engage students in learning: Per lab group (two to four students): • Foam Pipe insulator tube cut in half lengthwise • 4 Ring Stands • toothpicks • ball bearing
Language Function students will develop. Additional language demands and language supports: • Gravitational Potential Energy • Kinetic Energy • Energy Conversion
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their proposed procedure to answer the guiding questions. • Formal Assessment: Students will be formally assessed on how well they follow their proposed procedure and how they choose to analyze the data collected.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:

A. Students are presented with the guiding question and a list of available materials (2-3 min.)
    1. How can you design a 4-hill roller coaster track that will allow a ball bearing to make it from the top of the first hill to the top of the fourth hill without any outside force acting upon it?
B. Students design an experiment to gather data to answer the guiding question and make predictions for the outcome (5-7 min.)
C. Each group shares their design with the class. (5-10 min.)
    1. At least one group should share their predictions for the outcome.
    2. Students should give and receive feedback on experiment design from their peers.
D. Students perform their experiment and collect data. (10-15 min.)
E. Students refine their design and collect more data. (10-15 min.)
F. Students share their final designs with the class and explain what they learned. (5-10 min.)

Standard HS-PS3-3.

"Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, sound level or light meters, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]" (NYSSLS, 2016, p. 57).

This standard is an extension of the previous standard (HS-PS3-2). Therefore, there are no additional inquiry starter activities prescribed for this standard. Utilizing the activity listed under standard HS-PS3-2 will suffice.

Standard HS-PS3-4. [NOTE: This standard is typically covered in Chemistry curriculum] "Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.]" (NYSSLS, 2016, p. 57).

Ice Water Bath.

Activity description. Students will be tasked to determine how thermal energy is transferred between water and ice cubes. They will take periodic measurements of temperature in different parts of the ice water bath.

Activity rationale. This activity will introduce students to the concepts contained in the Second Law of Thermodynamics. Students will be given a loose set of procedures. Therefore, this activity follows POGIL structure.

Activity modifications. This activity could be done as an ongoing experiment throughout another lab. Using a single ice bath for the whole class, students would be assigned to take temperature readings at certain intervals. This could also be done as demonstration. If ice is not available, this activity should not be performed.

Suggested next steps. This would be an appropriate time to introduce students to the Second Law of Thermodynamics. It would also be appropriate to introduce the Kelvin scale and how it relates to thermal energy.

Lesson Plan.

Central Focus for the learning segment: • Second Law of Thermodynamics
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS3-4: Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.]
Learning Objectives associated with the content standards: • Students will be able to describe the transfer of thermal energy in a closed system.
Instructional Resources and Materials to engage students in learning: Per lab group (two to four students): • 1 gallon bucket of water • Ice • At least 4 thermometers • Timer
Language Function students will develop. Additional language demands and language supports: • Thermal Energy • Energy transfer • Temperature • Kelvin
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their adherence to the procedure. • Formal Assessment: Students will be formally assessed on their analysis of the energy transfer based on the data.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:

A. Students are presented with the POGIL directions to read through (2-3 min.)
B. Students follow the procedures (13-17 min.)
    1. Take the temperature of the water in four different places.
    2. Record that temperature as T_0.
    3. Add the ice to the bucket.
    4. Take the temperature in the same four places again after 45 seconds.
    5. Retake the temperature every 45 seconds until the temperature in all four places are equal.
C. Each group shares their results and data analysis. (5-10 min.)
D. Students come up with a general rule for the transfer of thermal energy. (5-10 min.)

Standard HS-PS3-5.

“Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. [Clarification Statement: Examples of models could include diagrams, texts, algebraic expressions, and drawings representing what happens when two charges of opposite polarity are near each other.] [Assessment Boundary: Assessment is limited to systems containing two objects.]” (NYSSLS, 2016, p. 57).

Charged Balloons.

Activity description. In this activity, students will charge two balloons with roughly equal static charge. They will then place a cotton ball between the balloons, being careful not to touch either balloon. Students will observe what happens to the cotton ball.

Activity rationale. This activity will demonstrate to students the effects of an electric field. This activity follows the guidelines of POGIL, since the procedures are set by the teacher.

Activity modifications. This activity requires very few materials, so there should be no need for any modifications

Suggested next steps. This would be an appropriate time to introduce students to the behaviors of Electric Fields

Lesson Plan.

Central Focus for the learning segment: • Electric Fields
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS3-5: Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. [Clarification Statement: Examples of models could include diagrams, texts, algebraic expressions, and drawings representing what happens when two charges of opposite polarity are near each other.] [Assessment Boundary: Assessment is limited to systems containing two objects.]
Learning Objectives associated with the content standards: • Students will be able to qualitatively describe the effects of an object traveling through an Electric Field
Instructional Resources and Materials to engage students in learning: Per lab group (two to four students): • Two balloons of equal volume and mass • Two patches of material suitable for charging the balloons • Two Ring Stands • Lengths of string to hang the balloons • Length of string connecting the two rings stands • Cotton balls
Language Function students will develop. Additional language demands and language supports: • Charge • Electrostatic Force
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their adherence to the procedures. • Formal Assessment: Students will be formally assessed on how they describe the effects on the cotton ball as it moves through the Electric Field
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:

A. Students are presented with the POGIL directions to read through (2-3 min.)
B. Students follow the procedures (5-10 min.)
    1. Hang the Balloons from the string stretched between the two ring stands
    2. Concurrently rub each balloon with a patch of material for 1 minute.
    3. Bring the cotton ball in between the two balloons, being careful not to touch either balloon.
    4. Make observations about the effects of the balloons on the cotton ball.
C. Each group shares their observations. (5-10 min.)
D. Students come up with a general rule for the behavior of the cotton ball in the Electric Field. (5-10 min.)

Magnetic Field.

Activity description. In this activity, students will examine the patterns of a Magnetic Field using a permanent magnet and a clear bag of iron fillings.

Activity rationale. This activity will qualitatively show students how Magnetic Fields are arranged around a bar magnet. The procedures are given to the students. Therefore, this activity is POGIL-based.

Activity modifications. This activity requires very few materials, so there should be no need for any modifications. However, if iron filings are not abundant, this could be done as a demonstration using either an overhead projector or a document camera.

Suggested next steps. This would be an appropriate time to introduce students to Magnetic Field and Magnetic Flux. There is an activity with HS-PS2-5 on Electromagnetic Induction that would be appropriate after this one.

Lesson Plan.

Central Focus for the learning segment: • Magnetic Fields
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS3-5: Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. [Clarification Statement: Examples of models could include diagrams, texts, algebraic expressions, and drawings representing what happens when two charges of opposite polarity are near each other.] [Assessment Boundary: Assessment is limited to systems containing two objects.]
Learning Objectives associated with the content standards: • Students will be able to qualitatively describe the patterns of a Magnetic Field.
Instructional Resources and Materials to engage students in learning: Per lab group (two to four students): • Bar magnet • Clear Bag of Iron Fillings
Language Function students will develop. Additional language demands and language supports: • Magnetic Field • Field Lines
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their adherence to the procedures. • Formal Assessment: Students will be formally assessed on how they describe the effects of the Magnetic Field on the iron filings.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.
Lesson Timeline: A. Students are presented with the POGIL directions to read through (2-3 min.) B. Students follow the procedures (5-10 min.) 1. Place the bar magnet on a flat surface. 2. Gently shake the bag of iron filings until you’ve made a thin layer of iron filings spread throughout the bag. 3. Place the bag down on top of the bar magnet. 4. Observe the iron filings. C. Each group shares their observations. (5-10 min.) D. Students come up with a general rule for pattern of a Magnetic Field. (5-10 min.)

Standard HS-PS3-6.

“Analyze data to support the claim that Ohm’s Law describes the mathematical relationship among the potential difference, current, and resistance of an electric circuit. [Clarification Statement: Emphasis should be on arrangements of series circuits and parallel circuits using conventional current.] [Assessment Boundary: Assessment is limited to direct current (DC) circuits.]” (NYSSLS, 2016, p. 57).

Ohm’s Law.

Activity description. Students will take measurements using a voltmeter and an ammeter of simple circuits using a variety of resistors. Students will the analyze the results to determine the relationship between Ohms, Volts, and Amps.

Activity rationale. This activity will guide students towards deriving Ohm’s Law. Students will be given a simple setup to duplicate with differing resistors See Figure 7 for the circuit diagram. Students will be given the procedure to follow. However, they will choose how they want to analyze the data to determine the relationship among Volts, Amps, and Ohms. This activity follows the POGIL structure.

Activity modifications. This activity does not require very much in the way of materials. However, it should be noted that this activity is designed to be done with small DC voltage, such as from an AA battery. Also, the resistor should not be any smaller than 0.5Ω.

Suggested next steps. The students should be able to derive Ohm’s Law based on their measurements. This would be an appropriate place to confirm that Ohm’s Law states: $R=V/I$.

***Lesson Plan*.**

Central Focus for the learning segment: • Ohm's Law
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS3-6: Analyze data to support the claim that Ohm's Law describes the mathematical relationship among the potential difference, current, and resistance of an electric circuit. [Clarification Statement: Emphasis should be on arrangements of series circuits and parallel circuits using conventional current.] [Assessment Boundary: Assessment is limited to direct current (DC) circuits.]
Learning Objectives associated with the content standards: • Students will be able to describe the relationship among Volts, Amps, and Ohms.
Instructional Resources and Materials to engage students in learning: Per lab group (two to four students): • AA battery • Wires • Voltmeter • Ammeter • Resistors ranging from 0.5Ω to 10Ω
Language Function students will develop. Additional language demands and language supports: • Volts • Amps • Ohms • Voltmeter • Ammeter • Resistor • EMF • Current
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their adherence to the procedure. • Formal Assessment: Students will be formally assessed on how well they analyze their data and how close they come to deriving Ohm's Law.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:

A. Students are presented with the POGIL directions to read through (2-3 min.)
B. Students follow the procedures (20-25 min.)
    1. Setup your circuit following the diagram.
    2. Record the readings on the Voltmeter and Ammeter and record the Ohms of the resistor
    3. Repeat the process for 5 more resistors.
    4. Analyze your data to determine the relationship between Volts & Amps, Volts & Ohms, and Amps & Ohms.
    5. Try to come up with a single equation using all three variables.
C. Each group shares their results and equation with the class. (10-115 min.)

Module 3: Waves and Electromagnetic Radiation

This module contains the six standards within the *Waves and Electromagnetic Radiation* section of the NYSSLS.

- HS-PS4-1 deals components of Mechanical Waves. There are five activities included that can be used individually or in conjunction with one another.
- HS-PS4-2 deals with digital transmission and storage of information. There are no activities included for this standard.
- HS-PS4-3 deals with the dual nature of electromagnetic radiation. There are no activities included.
- HS-PS4-4 deals with effects of different frequencies of electromagnetic radiation when it is absorbed by matter. There are no activities included.
- HS-PS4-5 deals with technological devices that use wave behavior and wave interactions with matter to transmit and capture information and energy. There are no activities included.
- HS-PS4-6 deals with geometric optics. There is one activity included.

Standard HS-PS4-1

"Use mathematical representations to support a claim regarding relationships among the period, frequency, wavelength, and speed of waves traveling and transferring energy (amplitude, frequency) in various media. [Clarification Statement: Examples of data could include descriptions of waves classified as transverse, longitudinal, mechanical, or standing, electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, seismic waves traveling through Earth, and direction of waves due to reflection and refraction.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]" (NYSSLS, 2016, p. 59)

Mechanical Waves: Properties of Reflection. This activity is based on AP Physics 1 Investigation 8: Mechanical Waves (The College Board, 2015, p. 159-177).

Activity description. Using video analysis and other methods, students will investigate the properties of both transverse and longitudinal waves to determine the relationship among period, frequency, wavelength, and speed. Students will design several investigations to examine reflection.

This lab requires students to investigate what will happen to a wave on a medium with a fixed end versus an end that is not fixed. Students should be able to see how the ability of the far end of the medium to move affects the behavior of the wave. Their investigation should result in a general rule for the behavior of a wave if the far end of the medium is fixed and another general rule for when it is not fixed. This investigation should result in some understanding of the properties of reflection.

Activity rationale. This investigation will introduce students to properties of reflection. Students will be presented with guiding questions to answer through student-designed investigation. Students will be responsible for designing the procedures to answer the guiding question. Prior to these experiments, there should be no direct instruction into the components of mechanical waves. Once students have completed these investigations they will have a stronger understanding of the physical relationships among these characteristics of mechanical waves. This common experience with mechanical waves will increase the likelihood that direct instruction of the equations governing mechanical wave characteristics will make a lasting impact. This is the basis for inquiry learning in science.

Activity modifications. Teachers may want to use parts of these investigations as inquiry-based labs to introduce mechanical waves to their classes, or they may remove parts of the lab to use as expository labs after more direct instruction. The population of students should be used to determine to what depth the inquiry starters will be effective. Some of these parts may also be done as a demonstration instead of student-designed lab activity.

Suggested next steps. Upon completing investigation, students should be able to make inferences about the properties of reflection of mechanical waves. At this point, it would be appropriate to introduce direct instruction governing these phenomena. This standard specifically addresses using mathematical representations. Students that share a common experience such as this will likely find deeper meaning in the explanations once they are introduced. Some of them may have already discovered the exact explanations during the experiments.

Lesson Plan.

Central Focus for the learning segment: • Properties of Reflection in Mechanical Waves
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the period, frequency, wavelength, and speed of waves traveling and transferring energy (amplitude, frequency) in various media. [Clarification Statement: Examples of data could include descriptions of waves classified as transverse, longitudinal, mechanical, or standing, electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, seismic waves traveling through Earth, and direction of waves due to reflection and refraction.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]
Learning Objectives associated with the content standards: • Students will be able to describe the effects of reflection on a wave pulse through a medium with a fixed end and how that differs from a medium without a fixed end.
Instructional Resources and Materials to engage students in learning: “Per lab group (two to four students): • Slinky or other common wave demonstrator (longer spring and tight coils with about a 1-inch diameter) or ball-link chain (2–3 meters in length; 2–3 mm diameter balls. Ball-link chain is good for creating transverse standing wave patterns; it can be found in hardware stores in varying sizes, such as the size used for lamp pull chains.). • Thick string, such as cotton package string (2–3 meters) • Video capture device (digital camera, smartphone, etc.). • Video analysis or graphical analysis software: This software allows students to wirelessly collect, analyze, and share sensor data from a data sharing source. • Meter stick • Stopwatch (if video analysis is not available) • (Optional) Ring stand, clamps, pulley, and calibrated masses • (Optional) Mechanical oscillator equipment that can setup standing waves on a string” (The College Board, 2015, p. 164)
Language Function students will develop. Additional language demands and language supports: • Reflection • Mechanical Wave • Frequency • Wavelength • Period • Wave Speed • Wave Equation

Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their proposed procedure to answer the guiding questions. • Formal Assessment: Students will be formally assessed on how well they follow their proposed procedure and how they choose to analyze the data collected.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.
Lesson Timeline: A. Students are presented with the guiding questions and a list of available materials (2-3 min.) 1. What happens to a wave pulse when it is sent through a medium with a fixed end? 2. What happens to a wave pulse when it is sent through a medium without a fixed end? B. Students design an experiment to gather data to answer the guiding questions and make predictions for the outcome (5-7 min.) C. Each group shares their design with the class. (5-10 min.) 1. At least one group should share their predictions for the outcome. 2. Students should give and receive feedback on experiment design from their peers. D. Students perform their experiments and collect data. (15-20 min.) E. Students analyze their data to come up with general rules for both types of reflections. (5-10 min.) F. Students share the general rules they have written based on their collected data. (5-10 min.)

Mechanical Waves: Properties of Interference. This activity is based on AP Physics 1 Investigation 8: Mechanical Waves (The College Board, 2015, p. 159-177).

Activity description. Using video analysis and other methods, students will investigate the properties of both transverse and longitudinal waves to determine the relationship among period, frequency, wavelength, and speed. Students will design several investigations to examine reflection.

This lab examines the effects of two waves meeting in the same medium. Students will design a procedure to investigate what happens when a second wave is produced on the same medium as the first. Students should collect data to determine a general rule for how the waves interact with each other. Through this, students should discover the properties of wave interference.

Activity rationale. This investigation will introduce students to properties of wave interference. Students will be presented with guiding questions to answer through student-designed investigation. Students will be responsible for designing the procedures to answer the guiding question. Prior to these experiments, there should be no direct instruction into the components of mechanical waves. Once students have completed these investigations they will have a stronger understanding of the physical relationships among these characteristics of mechanical waves. This common experience with mechanical waves will increase the likelihood that direct instruction of the equations governing mechanical wave characteristics will make a lasting impact. This is the basis for inquiry learning in science.

Activity modifications. Teachers may want to use parts of these investigations as inquiry-based labs to introduce mechanical waves to their classes, or they may remove parts of the lab to use as expository labs after more direct instruction. The population of students should be used to determine to what depth the inquiry starters will be effective. Some of these parts may also be done as a demonstration instead of student-designed lab activity.

Suggested next steps. Upon completing investigation, students should be able to make inferences about interference of mechanical waves. At this point, it would be appropriate to introduce direct instruction governing these phenomena. This standard specifically addresses using mathematical representations. Students that share a common experience such as this will likely find deeper meaning in the explanations once they are introduced. Some of them may have already discovered the exact explanations during the experiments.

Lesson Plan.

Central Focus for the learning segment:

- Properties of Interference in Mechanical Waves

Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].)

NYSSLS 2016 – HS-PS4-1:

Use mathematical representations to support a claim regarding relationships among the period, frequency, wavelength, and speed of waves traveling and transferring energy (amplitude, frequency) in various media. [Clarification Statement: Examples of data could include descriptions of waves classified as transverse, longitudinal, mechanical, or standing, electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, seismic waves traveling through Earth, and direction of waves due to reflection and refraction.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]

Learning Objectives associated with the content standards:

- Students will be able to describe the effects of interference on a wave pulse through a medium.

Instructional Resources and Materials to engage students in learning:

“Per lab group (two to four students):

- Slinky or other common wave demonstrator (longer spring and tight coils with about a 1-inch diameter) or ball-link chain (2–3 meters in length; 2–3 mm diameter balls. Ball-link chain is good for creating transverse standing wave patterns; it can be found in hardware stores in varying sizes, such as the size used for lamp pull chains.).
- Thick string, such as cotton package string (2–3 meters)
- Video capture device (digital camera, smartphone, etc.).
- Video analysis or graphical analysis software: This software allows students to wirelessly collect, analyze, and share sensor data from a data sharing source.
- Meter stick
- Stopwatch (if video analysis is not available)
- (Optional) Ring stand, clamps, pulley, and calibrated masses
- (Optional) Mechanical oscillator equipment that can setup standing waves on a string” (The College Board, 2015, p. 164)

Language Function students will develop. Additional language demands and language supports:

- Reflection
- Mechanical Wave
- Frequency
- Wavelength
- Period
- Wave Speed
- Wave Equation

Type of Student Assessments and what is being assessed:

- Informal Assessment: Students will be informally assessed on their proposed procedure to answer the guiding questions.
- Formal Assessment: Students will be formally assessed on how well they follow their proposed procedure and how they choose to analyze the data collected.

Relevant theories and/or research best practices:

- Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:

A. Students are presented with the guiding question and a list of available materials (2-3 min.)
    1. What happens to a wave pulse when it collides with a second wave pulse in the same medium?
B. Students design an experiment to gather data to answer the guiding questions and make predictions for the outcome (5-7 min.)
C. Each group shares their design with the class. (5-10 min.)
    1. At least one group should share their predictions for the outcome.
    2. Students should give and receive feedback on experiment design from their peers.
D. Students perform their experiments and collect data. (15-20 min.)
E. Students analyze their data to come up with general rules about wave interference. (5-10 min.)
F. Students share the general rules they have written based on their collected data. (5-10 min.)

Mechanical Waves: Speed of a Wave Pulse. This activity is based on AP Physics 1 Investigation 8: Mechanical Waves (The College Board, 2015, p. 159-177).

Activity description. Using video analysis and other methods, students will investigate the properties of both transverse and longitudinal waves to determine the relationship among period, frequency, wavelength, and speed. Students will design several investigations to examine reflection.

This lab exposes students to the speed of the wave pulses. Students will design three investigations during this part of the lab activity. The first design is to determine if the tension in the medium affects the wave speed. The second investigation is to determine if the amplitude of the wave affects the wave speed. The third designed investigation is to find out qualitatively how the speed of a wave changes as it transfers to a different medium. These activities should make use of video capture and analysis software, if available.

Activity rationale. This investigation will introduce students to wave speed. Students will be presented with guiding questions to answer through student-designed investigation. Students will be responsible for designing the procedures to answer the guiding question. Prior to these experiments, there should be no direct instruction into the components of mechanical waves. Once students have completed these investigations they will have a stronger understanding of the physical relationships among these characteristics of mechanical waves. This common experience with mechanical waves will increase the likelihood that direct instruction of the equations governing mechanical wave characteristics will make a lasting impact. This is the basis for inquiry learning in science.

Activity modifications. Teachers may want to use parts of these investigations as inquiry-based labs to introduce mechanical waves to their classes, or they may remove parts of the lab to use as expository labs after more direct instruction. The population of students should be used to determine to what depth the inquiry starters will be effective. Some of these parts may also be done as a demonstration instead of student-designed lab activity. If video capture and analysis software is not available, teachers may use the “Wave on a String” demo on the PhET website: http://phet.colorado.edu/en/simulation/wave-on-a-string.

Suggested next steps. Upon completing investigation, students should be able to make inferences about the speed of mechanical waves. At this point, it would be appropriate to introduce direct instruction governing these phenomena. This standard specifically addresses using mathematical representations. Students that share a common experience such as this will likely find deeper meaning in the explanations once they are introduced. Some of them may have already discovered the exact explanations during the experiments.

Lesson Plan.

Central Focus for the learning segment: • Speed of Mechanical Waves
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the period, frequency, wavelength, and speed of waves traveling and transferring energy (amplitude, frequency) in various media. [Clarification Statement: Examples of data could include descriptions of waves classified as transverse, longitudinal, mechanical, or standing, electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, seismic waves traveling through Earth, and direction of waves due to reflection and refraction.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]
Learning Objectives associated with the content standards: • Students will be able to describe the effects of tension, and amplitude on wave speed. • Students will be able to describe the changes in wave speed during transmission to a new medium.
Instructional Resources and Materials to engage students in learning: “Per lab group (two to four students): • Slinky or other common wave demonstrator (longer spring and tight coils with about a 1-inch diameter) or ball-link chain (2–3 meters in length; 2–3 mm diameter balls. Ball-link chain is good for creating transverse standing wave patterns; it can be found in hardware stores in varying sizes, such as the size used for lamp pull chains.). • Thick string, such as cotton package string (2–3 meters) • Video capture device (digital camera, smartphone, etc.). • Video analysis or graphical analysis software: This software allows students to wirelessly collect, analyze, and share sensor data from a data sharing source. • Meter stick • Stopwatch (if video analysis is not available) • (Optional) Ring stand, clamps, pulley, and calibrated masses • (Optional) Mechanical oscillator equipment that can setup standing waves on a string” (The College Board, 2015, p. 164)
Language Function students will develop. Additional language demands and language supports: • Reflection • Mechanical Wave • Frequency • Wavelength • Period • Wave Speed • Wave Equation

Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their proposed procedure to answer the guiding questions. • Formal Assessment: Students will be formally assessed on how well they follow their proposed procedure and how they choose to analyze the data collected.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:
A. Students are presented with the guiding questions and a list of available materials (2-3 min.)
    1. Is there a relationship between tension in the medium and wave speed?
    2. Is there a relationship between amplitude and wave speed?
    3. Does the wave speed change when the wave is transmitted into a new medium?
B. Students design experiments to gather data to answer the guiding questions and make predictions for the outcome (5-7 min.)
C. Each group shares their designs with the class. (5-10 min.)
    1. At least one group should share their predictions for the outcome.
    2. Students should give and receive feedback on experiment design from their peers.
D. Students perform their experiments and collect data. (15-20 min.)
E. Students analyze their data to come up with general rules for the three experiments. (5-10 min.)
F. Students share the general rules they have written based on their collected data. (5-10 min.)

Mechanical Waves: Properties of a Standing Wave. This activity is based on AP Physics 1 Investigation 8: Mechanical Waves (The College Board, 2015, p. 159-177).

Activity description. Using video analysis and other methods, students will investigate the properties of both transverse and longitudinal waves to determine the relationship among period, frequency, wavelength, and speed. Students will design several investigations to examine reflection.

This lab asks students to investigate standing waves using video capture and analysis. Students will design a method to create a standing wave. Depending on the medium used, students should be able to create the first two or three harmonics. They will then use what they observed to make inferences about harmonics of a standing wave.

Activity rationale. This investigation will introduce students to the concept of standing waves and harmonics. Students will be presented with guiding questions to answer through student-designed investigation. Students will be responsible for designing the procedures to answer the guiding question. Prior to these experiments, there should be no direct instruction into the components of mechanical waves. Once students have completed these investigations they will have a stronger understanding of the physical relationships among these characteristics of mechanical waves. This common experience with mechanical waves will increase the likelihood that direct instruction of the equations governing mechanical wave characteristics will make a lasting impact. This is the basis for inquiry learning in science.

Activity modifications. Teachers may want to use parts of these investigations as inquiry-based labs to introduce mechanical waves to their classes, or they may remove parts of the lab to use as expository labs after more direct instruction. The population of students should be used to determine to what depth the inquiry starters will be effective. Some of these parts may also be done as a demonstration instead of student-designed lab activity.

Suggested next steps. Upon completing investigation, students should be able to make inferences about the harmonics of standing mechanical waves. At this point, it would be appropriate to introduce direct instruction governing these phenomena. This standard specifically addresses using mathematical representations. Students that share a common experience such as this will likely find deeper meaning in the explanations once they are introduced. Some of them may have already discovered the exact explanations during the experiments.

Lesson Plan.

Central Focus for the learning segment: • Properties of Standing Mechanical Waves
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the period, frequency, wavelength, and speed of waves traveling and transferring energy (amplitude, frequency) in various media. [Clarification Statement: Examples of data could include descriptions of waves classified as transverse, longitudinal, mechanical, or standing, electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, seismic waves traveling through Earth, and direction of waves due to reflection and refraction.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]
Learning Objectives associated with the content standards: • Students will be able to describe the role of reflection in creating a standing wave. • Students will be able to describe the role of harmonics and frequency in standing waves.
Instructional Resources and Materials to engage students in learning: "Per lab group (two to four students): • Slinky or other common wave demonstrator (longer spring and tight coils with about a 1-inch diameter) or ball-link chain (2–3 meters in length; 2–3 mm diameter balls. Ball-link chain is good for creating transverse standing wave patterns; it can be found in hardware stores in varying sizes, such as the size used for lamp pull chains.). • Thick string, such as cotton package string (2–3 meters) • Video capture device (digital camera, smartphone, etc.). • Video analysis or graphical analysis software: This software allows students to wirelessly collect, analyze, and share sensor data from a data sharing source. • Meter stick • Stopwatch (if video analysis is not available) • (Optional) Ring stand, clamps, pulley, and calibrated masses • (Optional) Mechanical oscillator equipment that can setup standing waves on a string" (The College Board, 2015, p. 164)
Language Function students will develop. Additional language demands and language supports: • Reflection • Mechanical Wave • Frequency • Wavelength • Period • Wave Speed • Wave Equation

Type of Student Assessments and what is being assessed:

- Informal Assessment: Students will be informally assessed on their proposed procedure to answer the guiding questions.
- Formal Assessment: Students will be formally assessed on how well they follow their proposed procedure and how they choose to analyze the data collected.

Relevant theories and/or research best practices:

- Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:

A. Students are presented with the guiding questions and a list of available materials (2-3 min.)
    1. What is the role of reflection in creating a standing wave?
    2. Why is this called a standing wave?
    3. Is there a pattern between the harmonics and the frequency at which the waves are generated?

B. Students design experiments to gather data to answer the guiding questions and make predictions for the outcome (5-7 min.)

C. Each group shares their designs with the class. (5-10 min.)
    1. At least one group should share their predictions for the outcome.
    2. Students should give and receive feedback on experiment design from their peers.

D. Students perform their experiments and collect data. (15-20 min.)

E. Students analyze their data to come up with general rules for both types of reflections. (5-10 min.)

F. Students share the general rules they have written based on their collected data. (5-10 min.)

Mechanical Waves: Determining Speed of a Standing Wave. This activity is based on AP Physics 1 Investigation 8: Mechanical Waves (The College Board, 2015, p. 159-177).

Activity description. Using video analysis and other methods, students will investigate the properties of both transverse and longitudinal waves to determine the relationship among period, frequency, wavelength, and speed. Students will design several investigations to examine reflection.

This lab asks students to design a method to create a standing wave. Students should measure the period and/or wavelength of the different harmonics they create without the use of video capture. Using this data, students are asked to determine the relationship between frequency and wavelength. They are then asked to determine the speed of the wave using that information.

Activity rationale. This investigation will introduce students to the wave equation, which describes the mathematical relationship among speed, frequency and wavelength. Students will be presented with guiding questions to answer through student-designed investigation. Students will be responsible for designing the procedures to answer the guiding question. Prior to these experiments, there should be no direct instruction into the components of mechanical waves. Once students have completed these investigations they will have a stronger understanding of the physical relationships among these characteristics of mechanical waves. This common experience with mechanical waves will increase the likelihood that direct instruction of the equations governing mechanical wave characteristics will make a lasting impact. This is the basis for inquiry learning in science.

Activity modifications. Teachers may want to use parts of these investigations as inquiry-based labs to introduce mechanical waves to their classes, or they may remove parts of the lab to use as expository labs after more direct instruction. The population of students should be used to determine to what depth the inquiry starters will be effective. Some of these parts may also be done as a demonstration instead of student-designed lab activity.

Suggested next steps. Upon completing investigation, students should be able to make inferences about how wavelength and frequency affect the speed of mechanical waves. At this point, it would be appropriate to introduce direct instruction governing these phenomena. This standard specifically addresses using mathematical representations. Students that share a common experience such as this will likely find deeper meaning in the explanations once they are introduced. Some of them may have already discovered the exact explanations during the experiments.

Lesson Plan.

Central Focus for the learning segment: • Speed of Mechanical Waves
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the period, frequency, wavelength, and speed of waves traveling and transferring energy (amplitude, frequency) in various media. [Clarification Statement: Examples of data could include descriptions of waves classified as transverse, longitudinal, mechanical, or standing, electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, seismic waves traveling through Earth, and direction of waves due to reflection and refraction.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]
Learning Objectives associated with the content standards: • Students will be able to describe the relationship between frequency and wavelength. • Students will be able to determine the wave speed from a graphical interpretation.
Instructional Resources and Materials to engage students in learning: “Per lab group (two to four students): • Slinky or other common wave demonstrator (longer spring and tight coils with about a 1-inch diameter) or ball-link chain (2–3 meters in length; 2–3 mm diameter balls. Ball-link chain is good for creating transverse standing wave patterns; it can be found in hardware stores in varying sizes, such as the size used for lamp pull chains.). • Thick string, such as cotton package string (2–3 meters) • Video capture device (digital camera, smartphone, etc.). • Video analysis or graphical analysis software: This software allows students to wirelessly collect, analyze, and share sensor data from a data sharing source. • Meter stick • Stopwatch (if video analysis is not available) • (Optional) Ring stand, clamps, pulley, and calibrated masses • (Optional) Mechanical oscillator equipment that can setup standing waves on a string” (The College Board, 2015, p. 164)
Language Function students will develop. Additional language demands and language supports: • Reflection • Mechanical Wave • Frequency • Wavelength • Period • Wave Speed • Wave Equation

Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their proposed procedure to answer the guiding questions. • Formal Assessment: Students will be formally assessed on how well they follow their proposed procedure and how they choose to analyze the data collected.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:
A. Students are presented with the guiding questions and a list of available materials (2-3 min.)
    1. What is the relationship between frequency and wavelength?
    2. How can you calculate the speed of a wave mathematically without the use of video capture and analysis?
    3. How does this method compare with that of the video capture and analysis?
B. Students design experiments to gather data to answer the guiding questions and make predictions for the outcome (5-7 min.)
C. Each group shares their designs with the class. (5-10 min.)
    1. At least one group should share their predictions for the outcome.
    2. Students should give and receive feedback on experiment design from their peers.
D. Students perform their experiments and collect data. (15-20 min.)
E. Students analyze their data to come up with a general rule for the relationship between frequency and wavelength. (5-10 min.)
F. Students share the general rules they have written based on their collected data. (5-10 min.)

Standard HS-PS4-2

"Evaluate questions about the advantages of using a digital transmission and storage of information. [Clarification Statement: Examples of advantages could include that digital information is stable because it can be stored reliably in computer memory, transferred easily, and copied and shared rapidly. Disadvantages could include issues of easy deletion, security, and theft.]" (NYSSLS, 2016, p. 59).

Activity description. There is no viable inquiry-based activity that will introduce content to meet this standard.

Activity rationale. This standard deals with information that cannot be tested in a high school physics lab. To meet this standard, students will need either direct instruction or a research-based project, such as a term paper or WebQuest. There is no feasible way to give students hands-on experience to discover the advantages of digital transmission and storage.

Activity modifications. There are no suggested modifications.

Suggested next steps. Students should either be directly instructed, or guided through research that supports the advantages and disadvantages of using a digital transmission and storage of information.

Lesson Plan. None.

Standard HS-PS4-3

"Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model (quantum theory), and that for some situations one model is more useful than the other. [Clarification Statement: Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a phenomenon could include resonance, interference, diffraction, and photoelectric effect.] [Assessment Boundary: Assessment of the photoelectric effect is limited to qualitative descriptions.]" (NYSSLS, 2016, p. 59).

Activity description. There is no viable inquiry-based activity that will introduce content to meet this standard.

Activity rationale. This standard deals with information that cannot be tested in a high school physics lab. To meet this standard, students will need either direct instruction or a research-based project, such as a term paper or WebQuest. There is no feasible way to give students hands-on experience to discover that electromagnetic radiation can be described as both a wave or a particle.

Activity modifications. There are no suggested modifications.

Suggested next steps. Students should either be directly instructed, or guided through research that describes how and why electromagnetic radiation can be described using the wave or particle models.

Lesson Plan. None.

Standard HS-PS4-4

“Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. [Clarification Statement: Emphasis is on the idea that photons associated with different frequencies of light have different energies, and the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. Examples of published materials could include scientific journals, trade books, magazines, web resources, videos, and other passages that may reflect bias.] [Assessment Boundary: Assessment is limited to qualitative descriptions.]” (NYSSLS, 2016, p. 59).

Activity description. There is no viable inquiry-based activity that will introduce content to meet this standard.

Activity rationale. This standard deals with information that cannot be tested in a high school physics lab. To meet this standard, students will need a research-based project, such as a term paper or WebQuest. There is no feasible way to give students hands-on experience to discover how electromagnetic radiation of differing frequencies affects the matter into which it is absorbed. The standard itself asks students to evaluate published materials. This standard is best met with a writing prompt that requires research

Activity modifications. There are no suggested modifications.

Suggested next steps. Students should be guided through research that describes how different frequencies of electromagnetic radiation affect the matter into which they are absorbed.

Lesson Plan. None.

Standard HS-PS4-5

"Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. [Clarification Statement: Examples could include Doppler effect, solar cells capturing light and converting it to electricity; medical imaging; and communications technology.] [Assessment Boundary: Assessments are limited to qualitative information. Assessments do not include band theory.]" (NYSSLS, 2016, p. 59).

Activity description. There is no viable inquiry-based activity that will introduce content to meet this standard.

Activity rationale. This standard deals with information that cannot be tested in a high school physics lab. To meet this standard, students will need either direct instruction or a research-based project, such as a term paper or WebQuest. There is no feasible way to give students hands-on experience to discover the technical information about how some devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Activity modifications. There are no suggested modifications.

Suggested next steps. Students should either be directly instructed, or guided through research that describes the technical information about how some devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Lesson Plan. None.

Standard HS-PS4-6.

"Use mathematical models to determine relationships among the size and location of images, size and location of objects, and focal lengths of lenses and mirrors. [Clarification Statement: Emphasis should be on analyzing ray diagrams to determine image size and location.] [Assessment Boundary: Assessment is limited to analysis of plane, convex, and concave mirrors, and biconvex and biconcave lenses.]" (NYSSLS, 2016, p. 59)

Geometric Optics. This activity is based on AP Physics 2 Investigation 6: Geometric Optics (The College Board, 2015, p. 273-285).

Activity description. Students will design investigations to calculate the focal lengths of several converging lens. Students will collect data about object and image distances for each lens. They will then determine the best way to graph their data to see a relationship between the two pieces of data.

Activity rationale. The lens equation describes the relationship among the object distance, image distance and focal length of lens or mirror. The purpose of this investigation is to give students hands-on experience with different lenses and how their focal length determines the size and placement of the image. They do not need to know the lens equation prior to this investigation.

Activity modifications. Students do not need to measure the focal length of different lenses. It would be sufficient to give each group of students a single lens.

Suggested next steps. Once students understand the concept of focal length, they can be introduced to the lens equation and ray diagrams. The same principles that work for lens also work for mirrors.

Lesson Plan.

Central Focus for the learning segment: • Geometric Optics
Content Standard(s): NYS CCLS or Content Standards (List the number and text of the standard. If only a portion of a standard is being addressed, then only list the relevant part[s].) NYSSLS 2016 – HS-PS4-6: Use mathematical models to determine relationships among the size and location of images, size and location of objects, and focal lengths of lenses and mirrors. [Clarification Statement: Emphasis should be on analyzing ray diagrams to determine image size and location.] [Assessment Boundary: Assessment is limited to analysis of plane, convex, and concave mirrors, and biconvex and biconcave lenses.]
Learning Objectives associated with the content standards: • Students will be able describe the relationship among the focal length, object distance, and image distance when using a lens or mirror.
Instructional Resources and Materials to engage students in learning: "Per lab group (two to four students): • Light source such as a clear lamp with a lament or a candle (either wax or battery operated) • Converging lenses, focal length 15–25 cm • Lens holders • Meter sticks • Index cards for screen (5 x 7 inches or larger)" (The College Board, 2015, p. 164)
Language Function students will develop. Additional language demands and language supports: • Reflection • Refraction • Focal Point • Focal length • Converging Lens • Convex • Principal axis • Image distance • Object distance
Type of Student Assessments and what is being assessed: • Informal Assessment: Students will be informally assessed on their proposed procedure to answer the guiding questions. • Formal Assessment: Students will be formally assessed on how well they follow their proposed procedure and how they choose to analyze the data collected.
Relevant theories and/or research best practices: • Pritchard, J. S. (2016). Inquiry starters: Labs to introduce content.

Lesson Timeline:

A. Students are presented with the guiding questions and a list of available materials (2-3 min.)
    1. How can we determine the location and size of the image created by a converging lens?
    2. What factor about the lens most impacts the image location and size?

B. Students design experiments to gather data to answer the guiding questions and make predictions for the outcome (5-7 min.)

C. Each group shares their designs with the class. (5-10 min.)
    1. At least one group should share their predictions for the outcome.
    2. Students should give and receive feedback on experiment design from their peers.

D. Students perform their experiments and collect data. (15-20 min.)

E. Students analyze their data to and decide how best to graph the data to determine the relationship between object distance and image distance. (5-10 min.)

F. Students share their graphs and whether they found a general rule about the relationship between object and image distance. (5-10 min.)

Chapter 4 – Summary and Discussion

Conclusion

The NGSS are here. The New York State Board of Regents voted to adopt the draft NYSSLS in December 2016. The mandate is to begin implementation July 1, 2017. School districts and teachers have the rest of the 2016-2017 school year to figure out how they are going to make the changes to the curriculum necessary to meet the new standards. This project is a step in that direction. This project is a resource that Physics teachers can use to ensure they are teaching their students through a research-based method with hands-on activities that follow an inquiry-based approach.

Research has shown that students who learn by inquiry improve their achievement scores and retain the information longer than those who are taught through the traditional pedagogy of instruct-assess-move on to the next topic. These activities will encourage students to think like scientists. They will make discoveries and earn a deeper connection to the concepts.

This project is by no means a definitive collection of inquiry starters. There are any number of activities that could have been included. This was intended to be a start to the process of collecting lab activities that will move students towards meeting the standards. Teachers can add to this list of inquiry starters as they discover new activities that introduce the content within the standards. There also may be further topics relating to these standards not covered by this project. Teachers may feel free to use some, or none, of these activities. This collection does not include any activities that deal with Nature of Science or History of Science.

There are numerous standards within the P-12 NYSSLS. Teachers of all grade levels can use this project as a template to create compendia of activities suitable for their grade level and area of science.

Implications

The research reviewed within this paper overwhelmingly backs the use of inquiry. There is also data that supports the idea that students who discover learning, rather than repeating what they are told, gain a deeper understanding of the material. In some cases, students were also shown to retain the knowledge longer than those who learned by rote memorization. Utilizing any of these activities in a high school Physics class should lead to higher achievement scores, a narrowing of the achievement gap by race, gender, and SES. These activities should also lead to fewer students feeling like they are "not good at science." Inquiry labs such as these, help foster a growth mindset, as these labs are not about the results but the process and the learning that takes place. While some teachers may balk at the idea of spending time on inquiry for students to discover concepts for themselves due to the amount of content they are tasked with presenting, inquiry learning necessitates fewer hours spent instructing students. Teachers are even more valuable as facilitators during inquiry than as instructors during rote learning.

Final Thoughts

This project was conceived in mid-February 2016 and is approaching its completion in December 2016. The past 10 months of completing this project not only exposed me to the myriad standards within the NYSSLS, it also opened my eyes to many ways to incorporate inquiry in a Physics classroom. My certification will be in both Physics and Adolescent Special Education. No one knows what the future holds for me. Upon completing this project at the end of Master's coursework, I know that no matter what type of classroom in which I end up teaching, I will be able to include many opportunities for inquiry. I will strive for the entirety of my career to increase the opportunities for inquiry learning. These labs are just a beginning for me. This document will remain a live document for me. I will continue to add to it and modify activities as I have opportunities to introduce them to real students. This project has been a literature review and curriculum project, but once I start teaching, it will transform to action research. Someday this document may include a fifth chapter dedicated to the effectiveness of each lab in student learning.

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Figures

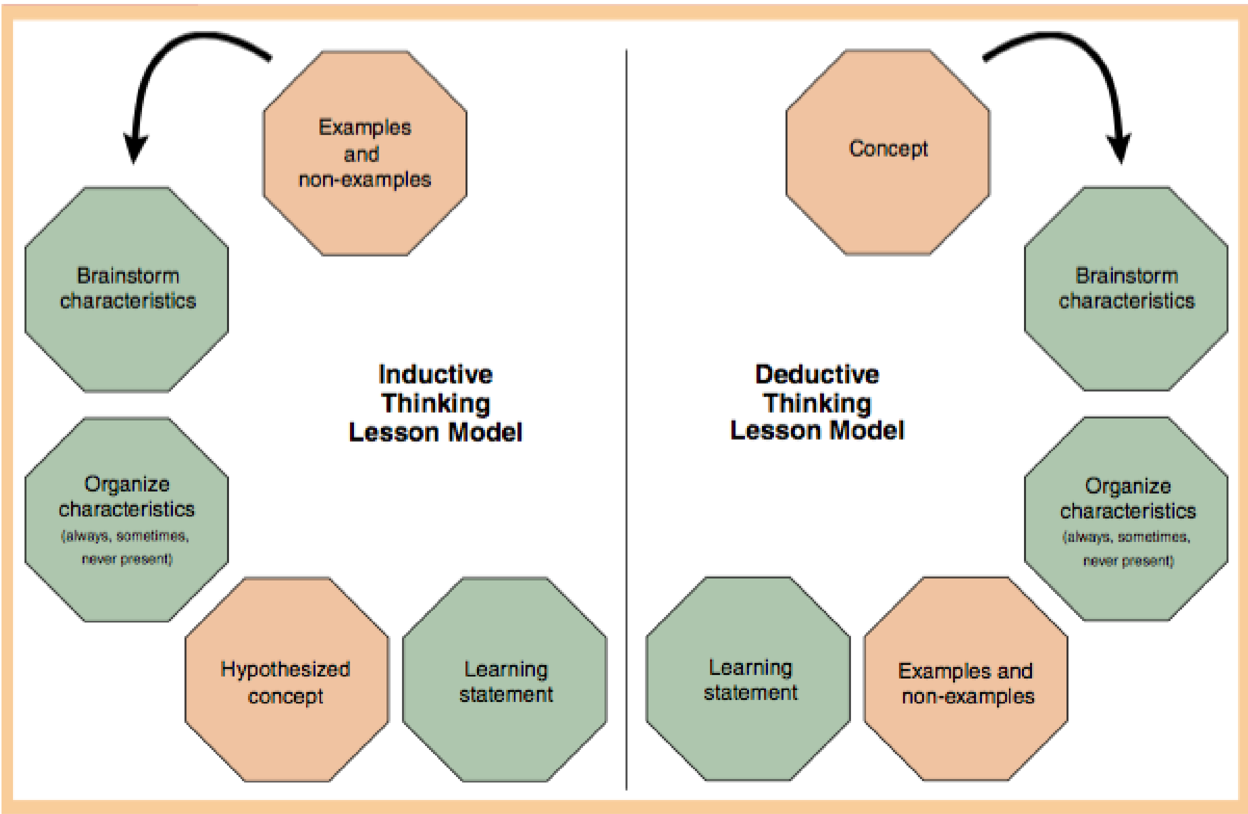

Figure 1. The difference between inductive and deductive thinking lesson models (Bilica & Flores, 2009, p. 37).

	Prelaboratory experience		Laboratory experience	Postlaboratory experience	
Level of inquiry	Proposes a problem or issue to be explored	Addresses or plans procedure to be used	Carries out the procedure	Supplies answers or conclusions	Uses outcomes to drive further instruction
0 Teacher is responsible for all activities.	Teacher	Teacher	Teacher	Teacher	Teacher
1 Teacher demonstrates. Students must research applications.	Teacher	Teacher	Teacher	Teacher	Students
2 Teacher demonstrates. Students supply their own answers, conclusions, and applications.	Teacher	Teacher	Teacher	Students	Students
3 Teacher initiates activity and provides procedure. Students conduct investigation and follow up.	Teacher	Teacher	Students	Students	Students
4 Desired level of inquiry Teacher poses problem. Students are responsible for all other activities.	Teacher/ Students	Students	Students	Students	Students
5 Total student involvement; no restriction on topics or methods.	Students	Students	Students	Students	Students

*Adapted from Priestly et al. 1998.

Figure 2. Inquiry continuum for shifting from cookbook labs (Gooding & Metz, 2012, p. 44).

Name ______________ Teacher/Block ______________ Date ______________

Criteria	Points possible	Points earned
Problem • Problem is stated as a question. • Independent and dependent variables are identified. • The control is identified (if necessary).	10	
Background Information • Includes a minimum of one paragraph about what information is already known about the problem or what was researched.	10	
Hypotheses • Predictions or solutions to the problem are stated using the "If________, then ________" format.	10	
Materials • All materials in the experiment are listed.	10	
Procedure • Step-by-step instructions are provided. • Instructions are detailed, allowing the experiment to be replicated. • Constant variables are used. • Multiple trials are performed.	20	
Results • Data table is titled and appropriate units are used. • Graph is titled and appropriate type is used. • Graph axes are properly labeled with the correct units.	20	
Conclusion • Includes a statement about what was learned about the problem. • Is supported by data from the results. • Describes reasons for support or rejection of the hypothesis. • Explains real-life connections.	20	
Overall lab report score	100	

Figure 3. Laboratory report rubric (Longo, 2011, p. 9)

Method	Required resources	Planning time and instructor involvement	Student resistance
Inquiry	None	Small	Minimal
Cases (individual)	Cases	Small (existing cases); considerable (original cases)	Minimal
Project-based (individual)	Facilities for experimental projects	Small (same project, no facilities maintenance); moderate (different projects, facilities maintenance[a]	Minimal
Just-in-time teaching	Web-based course management system	Moderate (continual need to adjust lesson plans to reflect student answers to pre-class questions)	Moderate
Cases (teams)	Cases	Considerable (team management[b])	Considerable[b]
Project-based (teams)	Facilities for experimental projects	Considerable (team management, facilities maintenancea)	Considerable[a,b]
Problem-based	Problems	Considerable (existing problems), extensive (original problems)[b]	Major[c]
Hybrid (problem/ project-based)	Problems, facilities for experimental projects	Considerable (existing problems), extensive (original problems)[a,b]	Major[c]

[a] Assuming that experimental facilities are required for student projects and that the instructor (as opposed to a technician) is involved in maintaining them.

[b] Assuming that cooperative learning principles are followed for team projects. If, for example, students can self-select teams and the instructor makes no effort to assess individual knowledge and performance or to intervene in team conflicts, the demands on the instructor are the same as for individual assignments using the same method.

[c] Resistance follows both from the burden of responsibility for their own learning placed on students and the additional demands imposed by cooperative learning. Hybrid methods may also involve problems of facilities maintenance.

Figure 4. Instructional demands imposed by inductive teaching methods (Prince & Felder, 2007, p. 17)

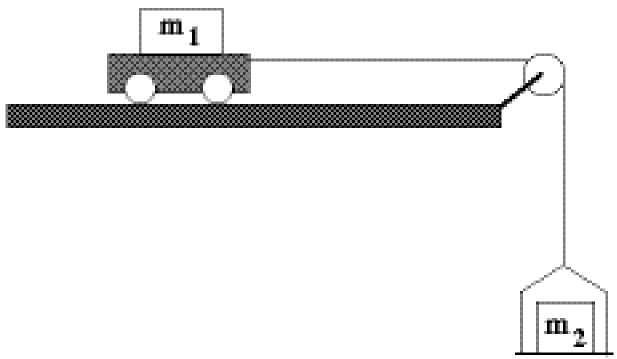

Figure 5. Modified Atwood's machine with a system consisting of a cart and a hanger with slotted masses.

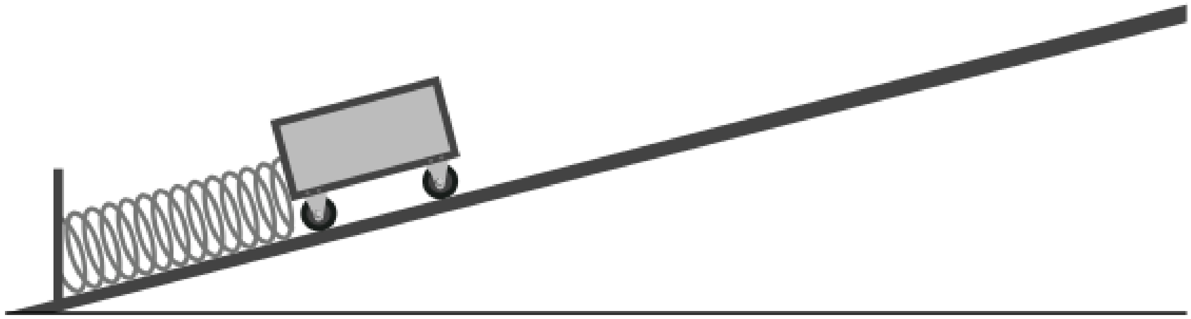

Figure 6. Ramp and spring-loaded cart.

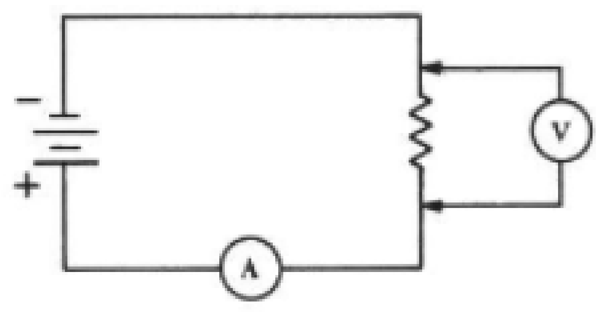

Figure 7. Simple circuit with one resistor, a voltmeter, and an ammeter.