



# AP<sup>®</sup> Physics 1: Algebra-Based Course Planning and Pacing Guide

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The College Board strongly encourages educators to make equitable access a guiding principle for their AP programs by giving all willing and academically prepared students the opportunity to participate in AP. We encourage the elimination of barriers that restrict access to AP for students from ethnic, racial and socioeconomic groups that have been traditionally underserved. Schools should make every effort to ensure their AP classes reflect the diversity of their student population. The College Board also believes that all students should have access to academically challenging course work before they enroll in AP classes, which can prepare them for AP success. It is only through a commitment to equitable preparation and access that true equity and excellence can be achieved.

## Welcome to the AP® Physics Course Planning and Pacing Guides

This guide is one of four course planning and pacing guides designed for AP® Physics 1 teachers. Each provides an example of how to design instruction for the AP course based on the author's teaching context (e.g., demographics, schedule, school type, setting).

These course planning and pacing guides highlight how the components of the *AP Physics Curriculum Framework* — the learning objectives, conceptual understandings, and science practices — are addressed in the course. Each guide also provides valuable suggestions for teaching the course, including the selection of resources, instructional activities such as laboratory investigations, and formative and summative assessments. The authors have offered insight into the *why* and *how* behind their instructional choices — displayed in boxes along the right side of the individual unit plans — to aid in course planning for AP Physics teachers.

The primary purpose of these comprehensive guides is to model approaches for planning and pacing curriculum throughout the school year. However, they can also help with syllabus development when used in conjunction with the resources created to support the AP Course Audit: the Syllabus Development Guide and the four Annotated Sample Syllabi. These resources include samples of evidence and illustrate a variety of strategies for meeting curricular requirements.



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## Madison County High School Danielsville, Georgia

School	Madison County High School is a traditional public high school located in a rural county just northeast of the University of Georgia. As the only high school in our county, we have a diverse student population and offer a wide variety of classes.
Student population	<p>In total, our student population averages about 1,400, with the following racial/ethnic demographics:</p> <ul style="list-style-type: none"> <li>• 81 percent Caucasian</li> <li>• 9 percent African American</li> <li>• 6 percent Hispanic</li> <li>• 1 percent Asian American</li> <li>• 3 percent multiracial</li> </ul> <p>About 58 percent of students receive free or reduced lunch, and on average 45 percent of our students enroll in college courses after graduation. Parents and guardians of our students represent a variety of professions, from farming to working in academia. AP course offerings and AP enrollment have recently been pushed as a school initiative, yet only a small subset of our students tend to challenge themselves with AP-level courses.</p>
Instructional time	The school year starts in early August and typically lasts until late May. The school operates on a modified seven-period schedule. Classes meet three times a week for approximately 50 minutes each day, with an additional fourth day of instruction lasting approximately 90 minutes. Total class time is about 240 minutes a week for the full school year.
Student preparation	An AP Physics course is typically offered to any 11th- or 12th-grade student who desires a rigorous math-based science course. To encourage enrollment, there are no specific course prerequisites. Therefore, students enrolled in the AP Physics 1 course have many different levels of preparation. Most students have had either chemistry or physical science, as well as biology and two years of required math (but not at any particular level). None of our AP Physics 1 students have had a previous introductory physics course. As a consequence, most AP Physics 1 students at Madison County High School enter the course with a need to develop the mathematical analysis skills and conceptual understandings required to succeed.
Primary planning resource	Walker, James. <i>Physics</i> . 4th ed. San Francisco: Pearson, 2010.

# Overview of the Course



AP Physics 1 is designed to be equivalent to the first semester of an introductory college-level algebra-based physics course. As AP Physics 1 is taught over a full school year, there is time for thorough, in-depth, student-centered inquiry activities that give me and my students flexibility and control over how they learn the course curriculum. I have implemented a modified flipped-classroom approach because I believe the most important thing we can do is empower our students to take ownership of their own learning.

At the start of each unit, students are given a list of the AP learning objectives along with a list of the suggested and required activities in the unit. The required activities are listed in this course planning and pacing guide; the suggested activities include assignments such as note-taking on my video lectures (which are available on my course Moodle site), basic research and note-taking using the Internet or a textbook, and practice sets or end-of-chapter problems for which I specify a set number of problems and allow the students to choose which to solve. Students are given the freedom to use alternate resources instead of completing the suggested activities, if they prefer. Students proceed through the activities at their own pace, working together on the laboratory investigations in small groups of two or three. Students record their observations and data in a laboratory notebook and write final reports when directed to do so. I set a date for the unit's summative assessment so students may plan their time both in and out of the classroom accordingly. Because my students are taking physics for the first time, I supply them with a high school text (Hewitt's *Conceptual Physics*) in addition to their college-level textbook (Walker's *Physics*). This allows them to begin with basic concepts as needed, before progressing to the higher-level text and problem sets.

Students spend more than 25 percent of instructional time completing laboratory activities. The majority of lab activities begin with open-ended questions that guide students to develop their own approach to addressing the problem at hand. In many cases, students have the option to investigate their own questions for the lab instead of those provided by me, as long as the students' questions address the specified learning objectives. They devote the majority of their in-class time to inquiry-based laboratory investigations, as most of their true learning occurs in this setting. Next to lab investigations, peer-group problem solving tends to occupy the greatest amount of in-class time, as my students are developing their problem-solving skills and need a lot of help from each other (and modeling from me).

Some of the activities in this course planning and pacing guide are identified specifically as formative assessments because they are especially appropriate for gauging student understanding of key concepts. However, every activity we perform in class is, to some extent, a formative assessment. This is a key advantage of the flipped-classroom approach: students learn the basic concepts on their own, usually at home, and they come to class ready to apply those concepts and ask questions about them. Since my students are working on different activities at their own pace, I strive to have one-on-one conversations with each student every day. During these discussions I act as a guide, directing each student toward subsequent activities that should help them reach the appropriate level of understanding and ability for each objective. Of course, not every student will be completely prepared for the summative assessment in the specified time frame. Therefore, I allow students to remediate and correct their unit tests (summative assessments) for half credit.

- Velocity of a Nonaccelerating Object
- What's Your Reaction Time?
- Initial Velocity of a Popper Toy
- Horizontally Launched Projectile Challenge
- Initial Velocity of a Toy Dart Launched at an Angle
- Acceleration Due to Gravity


**Guiding Questions:**

▼ What advantages are gained from the use of vectors, as opposed to scalars? ▼ How is velocity fundamentally different from speed, and why is this difference important when solving kinematics problems? ▼ How can accelerated motion in one and two dimensions be described qualitatively, quantitatively, and graphically? ▼ Why is free fall considered a special case of accelerated motion?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Express the motion of an object using narrative, mathematical, and graphical representations. [LO 3.A.1.1, SP1.5, SP 2.1, SP 2.2]</p> <p>Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [LO 3.A.2.1, SP 1.1]</p>	<p><b>Web</b> "Addition of Forces (Vectors)"  "Vector Addition"</p>	<p><b>Instructional Activity:</b>  Students investigate the PhET simulations (alone or in pairs) and discover what they are able to do and/or demonstrate. Students must first become familiar with the controls, and then they are instructed to try different scenarios, documenting what they attempt and the subsequent results. Student–teacher discussion follows to check for misconceptions and answer student questions.</p>
<p>Express the motion of an object using narrative, mathematical, and graphical representations. [LO 3.A.1.1, SP1.5, SP 2.1, SP 2.2]</p> <p>Design an experimental investigation of the motion of an object. [LO 3.A.1.2, SP 4.2]</p> <p>Analyze experimental data describing the motion of an object, and express the results of the analysis using narrative, mathematical, and graphical representations. [LO 3.A.1.3, SP 5.1]</p>	<p>Timing devices, metersticks, various objects that can be put into motion</p>	<p><b>Instructional Activity:</b>  In this introductory inquiry-based lab investigation, students are required to develop their own experimental design and analysis methods (including qualitative, quantitative, and graphical analysis) to determine the velocity of an object displaying nonaccelerated motion. A variety of objects (such as motorized cars, walking toys, and an air track) are made available in the classroom, but students are also encouraged to provide their own as appropriate. At the conclusion of their investigation, students present to the class a formal report that includes the following components: Purpose, Method, Assumptions, Data, Analysis, Conclusion, and Sources of Uncertainty.</p>
<p>Express the motion of an object using narrative, mathematical, and graphical representations. [LO 3.A.1.1, SP 1.5, SP 2.1, SP 2.2]</p>	<p><b>Web</b> "Kinematics of 1D Uniformly Accelerated Motion"  "The Moving Man"</p>	<p><b>Instructional Activity:</b>  These simulations provide students with the ability to control direction, initial velocity, and acceleration of a moving object. Students then watch what happens and examine graphs of the motion they created. Students are instructed to try different scenarios, documenting what they attempt and the subsequent results. Student–teacher discussion follows to check for misconceptions and answer student questions.</p>

*I utilize simulations after students have done some introductory reading/research and they are beginning to solve problems or answer conceptual questions. I find that using simulations helps students visualize what is happening (especially graphically) and aids in the development of problem-solving skills. Because I also discuss the simulations with students and check for misconceptions, they serve as a formative assessment tool as well.*

*I utilize open-ended labs as a tool for helping students develop creativity, logical problem-solving skills, independence, and critical-thinking abilities. At the beginning of the year, I provide quite a bit of support and guidance in the process. As the year progresses, I gradually provide less and less support so that students are successfully conducting complete lab activities (typically in pairs) with minimal (or no) teacher support.*


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<p>Express the motion of an object using narrative, mathematical, and graphical representations. [LO 3.A.1.1, SP1.5, SP 2.1, SP 2.2]</p> <p>Design an experimental investigation of the motion of an object. [LO 3.A.1.2, SP 4.2]</p>	Rulers or metersticks	<p><b>Instructional Activity:</b></p> <p>Students work in small groups to develop a method for calculating their average reaction time using only a ruler or meterstick. No methodology is provided. Students then measure their reaction times, calculate the average, and compare it with those of their classmates. The activity culminates with a physics problem for students to solve individually, utilizing their reaction time: A person is driving down a country lane at 25 m/s, when a deer suddenly jumps in front of the car. The deer is 65 m ahead, and when the driver hits the brakes, the deceleration of the car is <math>4.20 \text{ m/s}^2</math>. Does the car hit the deer?</p>
<p>Express the motion of an object using narrative, mathematical, and graphical representations. [LO 3.A.1.1, SP 1.5, SP 2.1, SP 2.2]</p> <p>Design an experimental investigation of the motion of an object. [LO 3.A.1.2, SP 4.2]</p> <p>Analyze experimental data describing the motion of an object, and express the results of the analysis using narrative, mathematical, and graphical representations. [LO 3.A.1.3, SP 5.1]</p>	Popper toys, metersticks	<p><b>Instructional Activity:</b></p> <p>Students are provided with a popper toy (a half sphere that will pop up when inverted and placed on a surface) and asked to determine its initial vertical velocity using nothing but a meterstick (no timing devices allowed). As this is an open-ended lab activity, students are provided with no methodology. Students work in pairs to develop a methodology, analysis, and final report.</p>
<p>Express the motion of an object using narrative, mathematical, and graphical representations. [LO 3.A.1.1, SP 1.5, SP 2.1, SP 2.2]</p> <p>Design an experimental investigation of the motion of an object. [LO 3.A.1.2, SP 4.2]</p> <p>Analyze experimental data describing the motion of an object, and express the results of the analysis using narrative, mathematical, and graphical representations. [LO 3.A.1.3, SP 5.1]</p>	Ramps that clamp to the bench top, marbles, photogates, metersticks	<p><b>Instructional Activity:</b></p> <p>Students work in small groups to predict the landing site of a projectile launched horizontally from a lab table. Students are provided with a ramp, a choice of marbles, and a photogate for measuring the velocity of the marble at the bottom of the ramp. After setting up the ramp, students perform measurements and calculations to predict where on the floor the marble will land after it rolls down the ramp and off the table. Students are not permitted to allow the marble to roll off the table while they are developing their predictions. Students position a bulls-eye target to mark the predicted landing spot. The target has a grade of 100 percent in the bull's-eye, with successively lower grades on the outer rings.</p>

*Teacher guidance and support should be provided as appropriate to each pair. This activity helps me determine how students are progressing with the use of kinematics equations in problem solving and their facility with Science Practices 4 and 5, which involve experimental design and analysis.*

*For this lab, I use a sheet of carbon paper that is placed upside down over the target so that it marks the target where the marble hits, making it easier to score. Since the students must be careful in their calculations and measurements, and many find this extremely nerve-racking, I do not require them to produce a formal lab report. I have also used this as a practical portion of the summative assessment with great success.*


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<p>Express the motion of an object using narrative, mathematical, and graphical representations. [LO 3.A.1.1, SP 1.5, SP 2.1, SP 2.2]</p> <p>Design an experimental investigation of the motion of an object. [LO 3.A.1.2, SP 4.2]</p> <p>Analyze experimental data describing the motion of an object, and express the results of the analysis using narrative, mathematical, and graphical representations. [LO 3.A.1.3, SP 5.1]</p> <p>Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [LO 3.A.2.1, SP 1.1]</p> <p>Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [LO 3.B.2.1, SP 1.1, SP 1.4, SP 2.2]</p>	<p>Spark timers, rulers, small masses, tape</p>	<p><b>Formative Assessment:</b></p> <p>Students are shown how to use a spark timer (a device that makes a mark on a length of ticker tape once every 60th of a second) and are provided with an example of a "good run." They then work in small groups to graphically determine the acceleration due to gravity in the classroom, using a spark timer and other provided materials.</p>

*This is usually a tricky lab for my students, but it is a wonderful formative assessment tool; while I'm providing the extra guidance the groups need, I am able to get a good sense for where each student's weaknesses lie. This helps me direct students toward review and remediation tailored to their individual needs. I try to ensure that each student attempts this lab at least one week before the scheduled summative assessment.*


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Learning Objectives	Materials	Instructional Activities and Assessments
<p>All learning objectives addressed in the unit are assessed on the summative assessment.</p>		<p><b>Summative Assessment:</b></p> <p>For the first summative assessment of the year, I provide a test with a format similar to that of the AP Physics 1 Exam. Students take a test consisting of both multiple-choice and free-response questions. One free-response question requires students to graph by hand and analyze data. A second free-response question requires students to develop an experimental methodology and analysis. For this second free-response question, I often ask students to develop a method to determine the acceleration of an Olympic sprinter during the first few seconds of a race. Multiple-choice questions focus more on logical problem-solving skills and inquiry-type analysis as opposed to rote memorization.</p>

*This summative assessment addresses all of the guiding questions for this unit.*

- Inertial Mass
- Weight Versus Mass
- The "Mu" of Your Block
- Hooke's Law

- Coffee Filter Terminal Velocity
- Friction on a Ramp
- Modified Atwood's Machine



## Guiding Questions:

▼ How can you utilize Newton's laws of motion to predict the behavior of objects? ▼ Do action-reaction force pairs (Newton's third law) have a cause-and-effect relationship? Why or why not? ▼ How can free-body diagrams be utilized in the analysis of physical interactions between objects? ▼ Why can't an object exert a force on itself?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration. [LO 1.C.1.1, SP 4.2]</p> <p>Design a plan for collecting data to measure gravitational mass and to measure inertial mass, and to distinguish between the two experiments. [LO 1.C.3.1, SP 4.2]</p>	Inertial mass trays, gram masses (100, 200, and 300 g), timing devices, masses of various size for unknowns	<p><b>Instructional Activity:</b></p> <p>Students discover the equivalence between gravitational mass and inertial mass by utilizing inertial mass trays (or "inertial balances"). Several objects with known masses, as well as one object of unknown mass, are provided, and students work in small groups to graphically determine the unknown mass without the use of spring scales or balances.</p>
<p>Design a plan for collecting data to measure gravitational mass and to measure inertial mass, and to distinguish between the two experiments. [LO 1.C.3.1, SP 4.2]</p> <p>Apply <math>\vec{F} = m\vec{g}</math> to calculate the gravitational force on an object with mass <math>m</math> in a gravitational field of strength <math>g</math> in the context of the effects of a net force on objects and systems. [LO 2.B.1.1, SP 2.2, SP 7.2]</p>	Spring scales calibrated in newtons, electronic balances	<p><b>Instructional Activity:</b></p> <p>Students investigate the relationship between mass, force, and acceleration, as well as the relationship between Newton's first law (<math>\vec{F} = m\vec{a}</math>) and weight (<math>\vec{W} = m\vec{g}</math>). Through the graphing of weight (<math>y</math>-axis) versus mass (<math>x</math>-axis) for a variety of objects, and the calculation of the resulting slope, students discover the acceleration due to gravity on Earth. Students are also asked to write an equation relating force, mass, and acceleration based upon their data and analysis.</p>
<p>Analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [LO 3.A.3.1, SP 6.4, SP 7.2]</p> <p>Describe a force as an interaction between two objects and identify both objects for any force. [LO 3.A.3.3, SP 1.4]</p> <p>Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [LO 3.B.2.1, SP 1.1, SP 1.4, SP 2.2]</p> <p>Make claims about various contact forces between objects based on the microscopic cause of those forces. [LO 3.C.4.1, SP 6.1]</p> <p>Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and therefore having certain directions. [LO 3.C.4.2, SP 6.2]</p>	Friction blocks (wood blocks with sides of various surface areas, hooks for dragging the block, and one side covered in a sticky matting), spring scales	<p><b>Instructional Activity:</b></p> <p>Students work in groups to discover that the coefficient of friction (<math>\mu</math>) between two objects is independent of the surface area in contact between the two objects. Students are given friction blocks and spring scales, and are asked to collect data and solve for the coefficient of friction for each side of the block. Students also draw free-body diagrams of the block being dragged. Then, each group presents its analysis of the coefficient of friction for each surface of the block, along with its conclusions about how surface area in contact may (or may not) affect the coefficient of friction. The groups then peer critique results and discuss any discrepancies before submitting formal reports (one report per group) for grading.</p>

Since we have not discussed simple harmonic motion yet, I usually give a brief introduction to period and frequency before students begin this activity.

I supply spring scales with units in newtons (N) for weight measurement, and an electronic balance for mass measurement in grams. If you have spring scales with both units, use correction fluid and relabel them so both sides read only in newtons. It's also important to make sure students convert grams to kilograms so the slope unit winds up being  $m/s^2$ .

Friction blocks typically have sticky matting on one side. Be sure to replace the matting occasionally, as it tends to get less sticky as it accumulates dirt over the years. Eventually it gets so slick that the students don't see much of a difference between the matted side and the smooth wooden sides. I use the matting made for lining kitchen cabinets, cut it to size, and glue it onto the blocks of wood.


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Learning Objectives	Materials	Instructional Activities and Assessments
<p>Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [LO 3.A.2.1, SP 1.1]</p> <p>Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [LO 3.A.4.1, SP 1.4, SP 6.2]</p> <p>Use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [LO 3.A.4.2, SP 6.4, SP 7.2]</p> <p>Analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [LO 3.A.4.3, SP 1.4]</p> <p>Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and therefore having certain directions. [LO 3.C.4.2, SP 6.2]</p>	<p>Set of springs, various small masses, rulers or metersticks</p>	<p><b>Instructional Activity:</b></p> <p>Working in small groups, students choose a spring and predict how the force exerted by the spring might change depending on the mass hung from it. They test this prediction and then develop a method of graphically determining the spring constant (<math>k</math>) utilizing Hooke's Law. Follow-up questions involve a free-body analysis of the forces at work when a mass is hanging at rest from the spring and analysis of the atomic-scale forces at work with comparison to those required for supporting an object from below.</p>

*If you use a set of springs designed for Hooke's law (available from many science supply companies), use those with higher spring constants for this lab. I find that the first time students use springs, they tend to hang objects of large mass from them, which can deform the springs and alter the spring constants. Later in the year, when they are more familiar with how to treat the springs, the lower spring constants work great for periodic motion.*


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Learning Objectives	Materials	Instructional Activities and Assessments
<p>Challenge a claim that an object can exert a force on itself. [LO 3.A.3.2, SP 6.1]</p> <p>Describe a force as an interaction between two objects and identify both objects for any force. [LO 3.A.3.3, SP 1.4]</p> <p>Predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations with acceleration in one dimension. [LO 3.B.1.1, SP 6.4, SP 7.2]</p> <p>Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [LO 3.A.4.1, SP 1.4, SP 6.2]</p> <p>Use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [LO 3.A.4.2, SP 6.4, SP 7.2]</p> <p>Analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [LO 3.A.4.3, SP 1.4]</p> <p>Evaluate using given data whether all the forces on a system or whether all the parts of a system have been identified. [LO 4.A.2.2, SP 5.3]</p>		<p><b>Instructional Activity:</b></p> <p>After a brief presentation of the traditional "horse and cart" problem, which seems to present a discrepant event pertaining to action-reaction force pairs, groups develop a solution to the problem, which they present to the class. Once all groups have presented their ideas, the class debates and attempts to develop a final solution they all agree upon. Finally, students individually research the problem and provide a clear, logical, and well-written explanation of the actual action-reaction force pairs involved and why Newton's third law is not broken.</p>
<p>Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [LO 3.A.2.1, SP 1.1]</p> <p>Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [LO 3.B.2.1, SP 1.1, SP 1.4, SP 2.2]</p> <p>Make claims about various contact forces between objects based on the microscopic cause of those forces. [LO 3.C.4.1, SP 6.1]</p>	Coffee filters, metersticks, timing devices	<p><b>Instructional Activity:</b></p> <p>A nested set of 7–10 coffee filters is presented to each group. Students are asked to use the nested set of filters to determine if and how mass affects terminal velocity. Students are also asked to create free-body diagrams for the coffee filters, showing both accelerated motion and terminal velocity, and to provide a qualitative analysis of what causes terminal velocity at the macroscopic and molecular levels.</p>

*Students should be aware that once the coffee filters are separated, they do not go back together as neatly. The change in shape around the rim is enough to drastically alter the shape, and thus terminal velocity, of a group of coffee filters.*


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▼ How can you utilize Newton's laws of motion to predict the behavior of objects? ▼ Do action-reaction force pairs (Newton's third law) have a cause-and-effect relationship? Why or why not? ▼ How can free-body diagrams be utilized in the analysis of physical interactions between objects? ▼ Why can't an object exert a force on itself?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [LO 3.A.2.1, SP 1.1]</p> <p>Reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [LO 3.B.1.3, SP 1.5, SP 2.2]</p> <p>Design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces. [LO 3.B.1.2, SP 4.2, SP 5.1]</p> <p>Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [LO 3.B.2.1, SP 1.1, SP 1.4, SP 2.2]</p>	<p>Ramps, spring scales or force sensors, smartphone inclinometer app and/or protractors</p>	<p><b>Instructional Activity:</b></p> <p>Working in small groups, students select an object that will remain at rest when placed on the provided ramp. They then design and implement a plan to indirectly determine the mass of the object. Students are expected to use free-body diagrams, analysis of the components of the object's weight into and along the surface of the ramp, and subsequent vector addition. The use of a spring scale or force sensor is allowed only for determination of the force required to set the object in motion along the ramp surface.</p>
<p>Analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [LO 3.A.3.1, SP 6.4, SP 7.2]</p> <p>Describe a force as an interaction between two objects and identify both objects for any force. [LO 3.A.3.3, SP 1.4]</p> <p>Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [LO 3.A.4.1, SP 1.4, SP 6.2]</p>	<p>Movie clip or animated short film</p>	<p><b>Formative Assessment:</b></p> <p>To assess whether students have a firm grasp of the applications of Newton's laws of motion, I present them with a visual scenario (usually a short video clip) and ask them to analyze and explain the events shown in terms of Newton's three laws. Additionally, students must state whether or not the scenario fully agrees with Newton's laws and support their answer using evidence from the video. I often use 5- to 10-minute clips from popular movies in which basic physical laws are clearly being defied, but animated short films also work well and are fun for students.</p>

*A smartphone can be used as the object on the ramp as well as the measuring device to determine the angle of the ramp if students download one of several free inclinometer apps.*

*Feedback about students' learning is provided through group discussion about the concepts presented in the video and through one-on-one discussion with me.*


**Guiding Questions:**

▼ How can you utilize Newton's laws of motion to predict the behavior of objects? ▼ Do action-reaction force pairs (Newton's third law) have a cause-and-effect relationship? Why or why not? ▼ How can free-body diagrams be utilized in the analysis of physical interactions between objects? ▼ Why can't an object exert a force on itself?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [LO 3.A.2.1, SP 1.1]</p> <p>Analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [LO 3.A.3.1, SP 6.4, SP 7.2]</p> <p>Predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations with acceleration in one dimension. [LO 3.B.1.1, SP 6.4, SP 7.2]</p> <p>Design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces. [LO 3.B.1.2, SP 4.2, SP 5.1]</p> <p>Reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [LO 3.B.1.3, SP 1.5, SP 2.2]</p> <p>Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [LO 3.B.2.1, SP 1.1, SP 1.4, SP 2.2]</p> <p>Evaluate using given data whether all the forces on a system or whether all the parts of a system have been identified. [LO 4.A.2.2, SP 5.3]</p>	<p>String, timing devices, metersticks, objects of various sizes (including books, blocks, and masses)</p>	<p><b>Summative Assessment:</b></p> <p>A modified Atwood's machine lab is used in place of a regular multiple-choice and/or free-response test. Students are given basic instructions for setting up a modified Atwood's machine. Students are also given four objectives to solve for:</p> <ol style="list-style-type: none"> <li>1. Acceleration of the system</li> <li>2. Final velocity of the system</li> <li>3. Tension in the string</li> <li>4. Coefficient of friction between the bench top and the dragged object</li> </ol> <p>(The order in which I ask for the four calculations is designed to enable students to figure out how to solve for <math>\mu</math>.) Students work together in their lab groups and turn in a formal lab report that details their analysis (both qualitatively and quantitatively) and includes a full discussion of potential error and uncertainty.</p>

*This summative assessment addresses the following guiding questions:*

- How can you utilize Newton's laws of motion to predict the behavior of objects?
- How can free-body diagrams be utilized in the analysis of physical interactions between objects?


**Guiding Questions:**

▼ Why do you stay in your seat on a roller coaster when it goes upside down in a vertical loop? ▼ How is the motion of a falling apple similar to that of the moon in orbit around the Earth? ▼ What conditions are necessary for a planet to obtain a circular orbit around its host star? ▼ How can Newton's second law of motion be related to the universal law of gravitation? ▼ How can the motion of the center of mass of a system be altered?

Learning Objectives	Materials	Instructional Activities and Assessments
Analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [LO 3.A.3.1, SP 6.4, SP 7.2]	Pieces of PVC pipe (3/4-inch diameter, 1 foot long), high-test fishing line, rubber stoppers of various sizes, timing devices, rulers or metersticks	<b>Instructional Activity:</b> Students working in small groups are challenged to determine the relationships among centripetal acceleration, centripetal force, mass, velocity, and radius. Students accomplish this using a device that they build based on provided instructions. They use the device to swing a rubber stopper at various speeds while keeping a hanging mass (another rubber stopper) stationary. The device has a fishing line threaded through a PVC pipe with rubber stoppers tied to both ends. Students carefully swing the upper stopper in a circle of constant radius while watching the lower (stationary) stopper to ensure it does not bob up and down. Formal reports presenting evidence and analysis (both qualitative and quantitative) of the results are exchanged with peer groups for critique before final submission for grading.
Design a plan for collecting data to measure gravitational mass and to measure inertial mass, and distinguish between the two experiments. [LO 1.C.3.1, SP 4.2]  Articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored. [LO 3.G.1.1, SP 7.1]		<b>Formative Assessment:</b> To get students thinking about the similarities and differences between gravitational mass and inertial mass, I assign small groups a research and writing activity in which they articulate ways the two are related using evidence from the "Inertial Mass" and "Weight Versus Mass" labs they performed previously. As an extension, students are also required to research and discuss the circumstances under which the gravitational force is considered to be dominant among the four main forces (electromagnetic, gravitational, weak nuclear, and strong nuclear), even though it is the weakest of these forces.

*Centripetal force and acceleration are important topics to explore before getting into orbital motion and deriving Kepler's laws.*

*I read students' written reports, and then I conference with groups to address misconceptions, answer student questions, and ensure all students are ready to progress.*

# Gravitation and Circular Motion

(continued)

## Unit 3:



### Guiding Questions:

▼ Why do you stay in your seat on a roller coaster when it goes upside down in a vertical loop? ▼ How is the motion of a falling apple similar to that of the moon in orbit around the Earth? ▼ What conditions are necessary for a planet to obtain a circular orbit around its host star? ▼ How can Newton's second law of motion be related to the universal law of gravitation? ▼ How can the motion of the center of mass of a system be altered?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Apply <math>\vec{F} = m\vec{g}</math> to calculate the gravitational force on an object with mass <math>m</math> in a gravitational field of strength <math>g</math> in the context of the effects of a net force on objects and systems. [LO 2.B.1.1, SP 2.2, SP 7.2]</p> <p>Apply <math>g = G\frac{M}{r^2}</math> to calculate the gravitational field due to an object with mass <math>M</math>, where the field is a vector directed toward the center of the object of mass <math>M</math>. [LO 2.B.2.1, SP 2.2]</p> <p>Approximate a numerical value of the gravitational field (<math>g</math>) near the surface of an object from its radius and mass relative to those of the Earth or other reference objects. [LO 2.B.2.2, SP 2.2]</p> <p>Use Newton's law of gravitation to calculate the gravitational force the two objects exert on each other and use that force in contexts other than orbital motion. [LO 3.C.1.1, SP 2.2]</p>	<p><b>Web</b> "Gravity Force Lab"</p>	<p><b>Instructional Activity:</b> Students working in small groups utilize the PhET simulation to do the following:</p> <ol style="list-style-type: none"> <li>1. Discover the relationship between masses of objects, the distance between them, and the gravitational force of attraction.</li> <li>2. Derive an equation that relates mass, distance, and the gravitational force of attraction.</li> <li>3. Determine the magnitude of the universal gravitational constant.</li> </ol> <p>Then, they must test their equation by determining the gravitational force exerted on their body by the Earth and comparing this force to their known weight in newtons. Finally, students are asked to use their equation and Newton's second law to derive an equation and solve for the gravitational field (<math>g</math>) at the Earth's surface.</p>
<p>Use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion (for circular orbital motion only in Physics 1). [LO 3.C.1.2, SP 2.2]</p>	<p><b>Web</b> "My Solar System"</p>	<p><b>Instructional Activity:</b> Students working in small groups use the simulation to investigate how a planet's mass, velocity, and distance from a star are related to the planet's orbit. Then they must predict a correct combination of parameters (mass, velocity, and distance) necessary to maintain a circular orbit around a star of whatever mass they choose. Students back up their prediction by deriving an equation relating the universal law of gravitation to centripetal force (showing their calculations) and by using the simulation to test their prediction.</p>


**Guiding Questions:**

▼ Why do you stay in your seat on a roller coaster when it goes upside down in a vertical loop? ▼ How is the motion of a falling apple similar to that of the moon in orbit around the Earth? ▼ What conditions are necessary for a planet to obtain a circular orbit around its host star? ▼ How can Newton's second law of motion be related to the universal law of gravitation? ▼ How can the motion of the center of mass of a system be altered?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system. [LO 4.A.3.1, SP 2.2]</p> <p>Use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system. [LO 4.A.3.2, SP 1.4]</p> <p>Make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. [LO 4.A.2.1, SP 6.4]</p> <p>Create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system. [LO 4.A.2.3, SP 1.4, SP 2.2]</p>	<p>Two wheels, one of which has four small masses hidden near the axis of rotation and one of which has the same amount of mass hidden near the outer edge</p>	<p><b>Instructional Activity:</b></p> <p>Students working in small groups are challenged to first discover a way to change the center of mass motion of a simple system from the outside of the system and then from the inside of the system. A demonstration involving wheels with hidden masses may be utilized as a discrepant event to get students asking questions (as the two seemingly identical objects roll down an incline at different rates). Students can use and manipulate the demonstration apparatus if they wish. Students are promised a special prize if they can develop a way to change the center of mass motion from within the system. A logical explanation (including mathematical and/or graphical proof) of any change in motion is required, as are any explanations that it is not possible.</p>
<p>All learning objectives addressed in the unit are assessed on the summative assessment.</p>		<p><b>Summative Assessment:</b></p> <p>Students take a test consisting of multiple-choice questions and two free-response items. The first free-response item requires students to derive one of Kepler's laws of orbital motion from basic physics equations. The second asks students to explain how the motion of a falling apple is similar to that of the moon in orbit around the Earth.</p>

*I encourage and reward creativity, but I ensure that my students realize that it is impossible to change the center of mass motion of a system without an external force acting on the system.*

*This summative assessment addresses all of the guiding questions for this unit.*

- What's Your Power?
- Q-tip Impulse
- Silly Putty Squash
- Jar of Sand Challenge
- Spring to Work
- 1-D Marble Collision
- Air Track Collisions
- Roller Coaster Design
- Egg Drop Challenge



### Guiding Questions:

▼ How are humans dependent upon transformations of energy? ▼ If you hold an object while you walk at a constant velocity, are you doing work on the object? Why or why not? ▼ What factors affect the collision of two objects, and how can you determine whether the collision is elastic or inelastic? ▼ How can changes in momentum be utilized to determine the forces applied to an object?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Set up a representation or model showing that a single object can only have kinetic energy and use information about that object to calculate its kinetic energy. [LO 5.B.1.1, SP 1.4, SP 2.2]</p> <p>Translate between a representation of a single object, which can only have kinetic energy, and a system that includes the object, which may have both kinetic and potential energies. [LO 5.B.1.2, SP 1.5]</p> <p>Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [LO 5.B.3.1, SP 2.2, SP 6.4, SP 7.2]</p> <p>Apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. [LO 5.B.3.3, SP 1.4, SP 2.2]</p> <p>Predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. [LO 5.B.5.5, SP 2.2, SP 6.4]</p>	<p>Students may use any materials available in the classroom, as appropriate</p>	<p><b>Instructional Activity:</b></p> <p>Students work in small groups to design and implement a plan for determining which student in the group is the “most powerful.” They are expected to make predictions, collect data, analyze work and power, and compare results. Students are also asked to analyze how their demonstration of power relies upon the presence of the Earth, and to contemplate how these exercises would be different in the absence of the Earth. Students submit a final analysis in which they compare results with predictions, explore potential reasons for discrepancies, and explain why some physical exercises are more powerful than others.</p>
<p>Predict the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [LO 3.D.2.2, SP 6.4]</p> <p>Analyze data to characterize the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [LO 3.D.2.3, SP 5.1]</p> <p>Design a plan for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time. [LO 3.D.2.4, SP 4.2]</p>	<p>Q-tips, large diameter straws, tape, metersticks or metric tape measures, timing devices</p>	<p><b>Instructional Activity:</b></p> <p>In this two-part activity, students are first given Q-tips and straws and challenged to see who can make a “blow-dart” Q-tip travel the farthest. We hold a class discussion to explain the physics behind this activity. In the second part of this activity, students must use their Q-tip blowgun to collect data and calculate the acceleration of the Q-tip in the straw and the time the Q-tip spends within the straw.</p>

*This is a great activity for getting students to contemplate how a single object can't have potential energy on its own, only kinetic energy.*

*I use large diameter straws from a warehouse club store, but some fast food chains have these larger straws as well. You may have to search for the perfect straw source.*


**Guiding Questions:**

▼ How are humans dependent upon transformations of energy? ▼ If you hold an object while you walk at a constant velocity, are you doing work on the object? Why or why not? ▼ What factors affect the collision of two objects, and how can you determine whether the collision is elastic or inelastic? ▼ How can changes in momentum be utilized to determine the forces applied to an object?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. [LO 5.D.1.5, SP 2.1, SP 2.2]</p> <p>Qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. [LO 5.D.2.1, SP 6.4, SP 7.2]</p> <p>Apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [LO 5.D.2.3, SP 6.4, SP 7.2]</p> <p>Apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of the object. [LO 3.E.1.4, SP 2.2]</p>	<p>Silly Putty, 1-kg masses, temperature probes, metersticks</p>	<p><b>Instructional Activity:</b></p> <p>Students working in small groups are given a setup in which a 1-kg mass is dropped from a height of 0.3 m onto a ball of Silly Putty with a temperature probe inserted in it. Before the mass is dropped, students predict the type of collision that will result and the evidence they expect to collect in support of their prediction. Once the experiment is run, students collaboratively analyze whether the results support or contradict their prediction and compose a written analysis using data, observations, and calculations from the experiment as support.</p>

*The change in gravitational potential energy of the 1-kg mass between its initial height and the height it bounces to after hitting the Silly Putty may be used as an approximation of the gain in internal energy of the Silly Putty. Using Koser's calculation of the specific heat of Silly Putty —  $3000 \text{ J/kg} \cdot \text{C}^\circ$  — and the measured change in temperature, the expected change in internal kinetic energy may be calculated.*


**Guiding Questions:**

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Learning Objectives	Materials	Instructional Activities and Assessments
<p>Model verbally or visually the properties of a system based on its substructure and relate this to changes in the system properties over time as external variables are changed. [LO 1.A.5.1, SP 1.1, SP 7.1]</p> <p>Apply the concepts of conservation of energy and the work-energy theorem to determine qualitatively and/or quantitatively that work done on a two-object system in linear motion will change the kinetic energy of the center of mass of the system, the potential energy of the systems, and/or the internal energy of the system. [LO 4.C.2.2, SP 1.4, SP 2.2, SP 7.2]</p> <p>Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [LO 5.A.2.1, SP 6.4, SP 7.2]</p> <p>Describe and make predictions about the internal energy of systems. [LO 5.B.4.1, SP 6.4, SP 7.2]</p> <p>Calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [LO 5.B.4.2, SP 1.4, SP 2.1, SP 2.2]</p> <p>Make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). [LO 5.B.5.4, SP 6.4, SP 7.2]</p>	<p>Temperature probes, jars of sand (one-third full)</p>	<p><b>Instructional Activity:</b></p> <p>Students working in small groups are challenged to increase the internal kinetic energy of a jar of sand from within the system, and then from outside the system. No heating devices, such as hair dryers, may be utilized. Data must be collected as evidence of any change in the internal energy of the jar of sand. Each group must provide a written analysis of their success and/or failure on each objective, including evidence from their attempts.</p>

*As an incentive and to reward creativity, prizes may be offered to groups that are first to arrive at an effective solution and/or that provide the most creative solutions.*


**Guiding Questions:**

▼ How are humans dependent upon transformations of energy? ▼ If you hold an object while you walk at a constant velocity, are you doing work on the object? Why or why not? ▼ What factors affect the collision of two objects, and how can you determine whether the collision is elastic or inelastic? ▼ How can changes in momentum be utilized to determine the forces applied to an object?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Design an experiment and analyze graphical data in which interpretations of the area under a force-distance curve are needed to determine the work done on or by the object or system. [LO 5.B.5.2, SP 4.2, SP 5.1]</p> <p>Predict and calculate from graphical data the energy transfer to or work done on an object or system from information about a force exerted on the object or system through a distance. [LO 5.B.5.3, SP 1.4, SP 2.2, SP 6.4]</p>	<p>Set of springs, rulers or metersticks, small masses</p>	<p><b>Instructional Activity:</b></p> <p>Hooke's law is revisited to challenge students in the use of force-versus-distance graphs for the determination of work done on (or by) a spring. Each small group is given a spring and a variety of masses, and students must determine a graphical way of predicting the work done on the spring by each mass. Then, given a specific amount of work (randomly assigned), students must predict what mass is required to produce that amount of work and what displacement the mass will give the spring. In the final stage of this activity, students must design and implement a plan to test their prediction. Each group's percent error determines the grade they receive for the lab.</p>


**Guiding Questions:**

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Learning Objectives	Materials	Instructional Activities and Assessments
<p>Make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions. [LO 5.D.1.1, SP 6.4, SP 7.2]</p> <p>Apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Solve qualitatively and/or quantitatively for one-dimensional situations and only qualitatively in two-dimensional situations. [LO 5.D.1.2, SP 2.2, SP 3.2, SP 5.1, SP 5.3]</p> <p>Apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy. [LO 5.D.1.3, SP 2.1, SP 2.2]</p> <p>Design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome. [LO 5.D.1.4, SP 4.2, 5.1, SP 5.3, SP 6.4]</p>	<p>Metal ramps that clamp to the bench top, marbles, metersticks</p>	<p><b>Instructional Activity:</b></p> <p>Students work in small groups to demonstrate a one-dimensional collision. They roll a marble down a metal ramp (clamped to the lab bench top) so that the marble collides with an identical marble at rest at the end of the ramp. Students must then determine whether or not momentum is conserved. A lab report analyzing the experiment both qualitatively and quantitatively is required. In the report, students are expected to incorporate discussion of the collision type they observed and to support their discussion with evidence from the experiment.</p>


**Guiding Questions:**

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Learning Objectives	Materials	Instructional Activities and Assessments
<p>Apply mathematical routines to calculate the change in momentum of a system by analyzing the average force exerted over a certain time on the system. [LO 4.B.2.1, SP 2.2]</p> <p>Perform analysis on data presented as a force-time graph and predict the change in momentum of a system. [LO 4.B.2.2, SP 5.1]</p> <p>Plan data collection strategies to test the law of conservation of momentum in a two-object collision that is elastic or inelastic and analyze the resulting data graphically. [LO 5.D.2.2, SP 4.1, SP 4.2, SP 5.1]</p> <p>Analyze data that verify conservation of momentum in collisions with and without an external friction force. [LO 5.D.2.4, SP 4.1, SP 4.2, SP 4.4, SP 5.1, SP 5.3]</p>	<p>Air track and carts, force sensors, timing devices, metersticks</p>	<p><b>Instructional Activity:</b></p> <p>Working in small groups, students collide air-track carts of equal mass and then unequal mass, in both elastic and inelastic collisions. They use these activities to investigate the differences between elastic and inelastic collisions, as well as to predict and calculate changes in momentum from force and time measurements and force-time graphs. Students must respond to prompts such as the following:</p> <ol style="list-style-type: none"> <li>1. After graphing average force over time for each collision, determine the change in momentum.</li> <li>2. Is total momentum always conserved? Why or why not?</li> <li>3. How do your data for one-dimensional collisions on the air track compare to those from the one-dimensional collision between marbles in the previous activity? Include specific examples to support your conclusions.</li> </ol>


**Guiding Questions:**

▼ How are humans dependent upon transformations of energy? ▼ If you hold an object while you walk at a constant velocity, are you doing work on the object? Why or why not? ▼ What factors affect the collision of two objects, and how can you determine whether the collision is elastic or inelastic? ▼ How can changes in momentum be utilized to determine the forces applied to an object?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Make predictions about the changes in kinetic energy of an object based on considerations of the direction of the net force on the object as the object moves. [LO 3.E.1.1, SP 6.4, SP 7.2]</p> <p>Use net force and velocity vectors to determine qualitatively whether kinetic energy of an object would increase, decrease, or remain unchanged. [LO 3.E.1.2, SP 1.4]</p> <p>Use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether kinetic energy of that object would increase, decrease, or remain unchanged. [LO 3.E.1.3, SP 1.4, SP 2.2]</p> <p>Predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system. [LO 4.C.1.2, SP 6.4]</p> <p>Make predictions about the changes in the mechanical energy of a system when a component of an external force acts parallel or antiparallel to the direction of the displacement of the center of mass. [LO 4.C.2.1, SP 6.4]</p> <p>Calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. [LO 5.B.2.1, SP 1.4, SP 2.1]</p> <p>Predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., recognize that interactions within a system do not affect the center of mass motion of the system and determine that there is no external force). [LO 5.D.3.1, SP 6.4]</p>	<p>Roller coaster building materials (marbles and/or small balls, index cards, and pipe insulation cut in half) or roller coaster design and analysis software</p>	<p><b>Formative Assessment:</b></p> <p>To assess understanding of energy and momentum conservation, as well as the work-energy and impulse-momentum theorems, I have students work in small groups to design, predict the performance of, and test a roller coaster. The prediction of the performance of the coaster (before testing) includes free-body diagrams at each peak and valley, and at positions in between. Performance of the roller coaster (before and after testing) is analyzed both qualitatively and quantitatively, with a final comparison explaining contradictions between the predicted and actual performance. Students must address how the performance of their coaster would be affected if the entire ride were encapsulated in a glass dome and set in motion horizontally at 100 m/s in a region with no external forces.</p>

*Feedback is provided through student–teacher discussions to address misconceptions and student questions. In-depth feedback is essential on this lab in order to prepare students for the summative assessment.*


**Guiding Questions:**

▼ How are humans dependent upon transformations of energy? ▼ If you hold an object while you walk at a constant velocity, are you doing work on the object? Why or why not? ▼ What factors affect the collision of two objects, and how can you determine whether the collision is elastic or inelastic? ▼ How can changes in momentum be utilized to determine the forces applied to an object?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of the object. [LO 3.E.1.4, SP 2.2]</p> <p>Calculate the total energy of a system and justify the mathematical routines used in the calculation of component types of energy within the system whose sum is the total energy. [LO 4.C.1.1, SP 1.4, SP 2.1, SP 2.2]</p> <p>Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. [LO 5.B.3.2, SP 1.4, SP 2.2]</p> <p>Calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [LO 5.B.4.2, SP 1.4, SP 2.1, SP 2.2]</p> <p>Design an experiment and analyze data to examine how a force exerted on an object or system does work on the object or system as it moves through a distance. [LO 5.B.5.1, SP 4.2, SP 5.1]</p> <p>Justify the selection of data needed to determine the relationship between the direction of the force acting on an object and the change in momentum caused by that force. [LO 3.D.1.1, SP 4.1]</p> <p>Justify the selection of routines for the calculation of the relationships between changes in momentum of an object, average force, impulse, and time of interaction. [LO 3.D.2.1, SP 2.1]</p> <p>Calculate the change in linear momentum of a two-object system with constant mass in linear motion from a representation of the system (data, graphs, etc.). [LO 4.B.1.1, SP 1.4, SP 2.2]</p> <p><i>(learning objectives continue)</i></p>		<p><b>Summative Assessment:</b></p> <p>Each lab group is tasked with engineering a device capable of protecting an egg from destruction when dropped off the back of the football stadium bleachers (or any comparable height—approximately two to three stories). Students must test their devices, record data, and submit a full analysis of the performance of their device. Each analysis must address work, energy, impulse, power, momentum changes, collision type, and forces experienced by the egg during the drop and upon impact.</p>

*This summative assessment addresses the following guiding questions:*

- *How are humans dependent upon transformations of energy?*
- *What factors affect the collision of two objects, and how can you determine whether the collision is elastic or inelastic?*
- *How can changes in momentum be utilized to determine the forces applied to an object?*


**Guiding Questions:**

▼ How are humans dependent upon transformations of energy? ▼ If you hold an object while you walk at a constant velocity, are you doing work on the object? Why or why not? ▼ What factors affect the collision of two objects, and how can you determine whether the collision is elastic or inelastic? ▼ How can changes in momentum be utilized to determine the forces applied to an object?

Learning Objectives	Materials	Instructional Activities and Assessments
<p><i>(continued)</i></p> <p>Find the change in linear momentum for a constant-mass system using the product of the mass and the change in velocity of the center of mass. [LO 4.B.1.2, SP 5.1]</p> <p>Classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values. [LO 5.D.2.5, SP 2.1, SP 2.2]</p>		

- Torque on a Stick
- Seesaw Challenge
- Playground Merry-Go-Round
- Mini Merry-Go-Rounds



## Guiding Questions:

▼ What are the conditions necessary for two people with significant differences in mass to balance on a seesaw? ▼ What are the conditions necessary for static equilibrium? ▼ In what ways are rotational motion and linear motion related? ▼ What are the relationships among angular momentum, angular velocity, angular acceleration, rotational inertia, and torque?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Use representations of the relationship between force and torque. [LO 3.F.1.1, SP 1.4]</p> <p>Compare the torques on an object caused by various forces. [LO 3.F.1.2, SP 1.4]</p> <p>Estimate the torque on an object caused by various forces in comparison to other situations. [LO 3.F.1.3, SP 2.3]</p> <p>Design an experiment and analyze data testing a question about torques in a balanced rigid system. [LO 3.F.1.4, SP 4.1, SP 4.2, SP 5.1]</p> <p>Calculate torques on a two-dimensional system in static equilibrium by examining a representation or model (such as a diagram or physical construction). [LO 3.F.1.5, SP 1.4, SP 2.2]</p>	<p>Metersticks with holes drilled every 10 centimeters, small hanging masses</p>	<p><b>Instructional Activity:</b></p> <p>In this activity, students work in groups to discover the relationship between force and torque. Students are given hooked masses and a meterstick with predrilled holes, and they must create as many different configurations as they can that balance the stick horizontally. Then students calculate the torques produced (clockwise and counterclockwise) in each configuration. Follow-up questions include the following:</p> <ol style="list-style-type: none"> <li>1. Does the angle at which a force is applied affect the total torque?</li> <li>2. You are stranded in a situation where you need to loosen a rusty bolt. You have a wrench, but using it you are still unable to apply enough torque to loosen the bolt. You also have some pieces of steel pipe. How can you loosen the bolt without much effort?</li> </ol>
<p>Calculate torques on a two-dimensional system in static equilibrium, by examining a representation or model (such as a diagram or physical construction). [LO 3.F.1.5, SP 1.4, SP 2.2]</p>	<p>Sawhorse, wooden board (8 to 10 feet long and 1.5 to 2 inches thick), meterstick or measuring tape</p>	<p><b>Formative Assessment:</b></p> <p>A board, with the center of mass clearly marked, is balanced on a sawhorse to create a “seesaw.” I ask two student volunteers who are willing to sit on the seesaw to share their mass with the class. Students work in groups to calculate exactly where the volunteer with the greater mass should sit in order to balance with the volunteer of lesser mass, if the volunteer with lesser mass is sitting at one end of the seesaw, farthest from the axis of rotation. Once student groups have completed their calculations, the volunteers test each group’s calculation by sitting at the appropriate locations on the seesaw. Success is determined by how well the two people balance on the seesaw.</p>

*The PhET simulation “Balancing Act” may be used in place of or in addition to this activity.*

*I obtain feedback about student learning by monitoring each group’s discussion. I then suggest further practice and preparation to individual students as appropriate.*

*I explain the procedure before requesting volunteers. If many students wish to volunteer, I assign each group to perform calculations for a different pair of volunteers. I follow appropriate safety procedures, including testing the seesaw prior to use and instructing volunteers to communicate when sitting and standing. Volunteers should not tilt the seesaw back and forth.*


**Guiding Questions:**

▼ What are the conditions necessary for two people with significant differences in mass to balance on a seesaw? ▼ What are the conditions necessary for static equilibrium? ▼ In what ways are rotational motion and linear motion related? ▼ What are the relationships among angular momentum, angular velocity, angular acceleration, rotational inertia, and torque?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object. [LO 3.F.3.2, SP 2.1]</p> <p>Plan data collection and analysis strategies designed to test the relationship between torques exerted on an object and the change in angular momentum of that object. [LO 3.F.3.3, SP 4.1, SP 4.2, SP 5.1, SP 5.3]</p>	<p><b>Web</b>            “Lady Bug: Angular Kinematics”            and “Ladybug Revolution”</p>	<p><b>Instructional Activity:</b>            “Lady Bug: Angular Kinematics,” a guided-inquiry activity that involves the “Ladybug Revolution” simulation, is used to help students discover the basics of rotational kinematics. Angular velocity, angular acceleration, and the relationships of the angular kinematic equations to their linear counterparts are investigated. Answers to questions embedded within the activity are submitted for grading, and student–teacher discussions are held as needed to address student misconceptions.</p>


**Guiding Questions:**

▼ What are the conditions necessary for two people with significant differences in mass to balance on a seesaw? ▼ What are the conditions necessary for static equilibrium? ▼ In what ways are rotational motion and linear motion related? ▼ What are the relationships among angular momentum, angular velocity, angular acceleration, rotational inertia, and torque?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Make predictions about the change in the angular velocity about an axis for an object when forces exerted on the object cause a torque about that axis. [LO 3.F.2.1, SP 6.4]</p> <p>Plan data collection and analysis strategies designed to test the relationship between a torque exerted on an object and the change in angular velocity of that object about an axis. [LO 3.F.2.2, SP 4.1, SP 4.2, SP 5.1]</p> <p>Describe a model of a rotational system and use that model to analyze a situation in which angular momentum changes due to interaction with other objects or systems. [LO 4.D.2.1, SP 1.2, SP 1.4]</p> <p>Plan a data collection and analysis strategy to determine the change in angular momentum of a system and relate it to interactions with other objects and systems. [LO 4.D.2.2, SP 4.2]</p> <p>Use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular momentum. [LO 4.D.3.1, SP 2.2]</p> <p>Plan a data collection strategy designed to test the relationship between the change in angular momentum of a system and the product of the average torque applied to the system and the time interval during which the torque is exerted. [LO 4.D.3.2, SP 4.1, SP 4.2]</p> <p>Plan data collection strategies designed to establish that torque, angular velocity, angular acceleration, and angular momentum can be predicted accurately when the variables are treated as being clockwise or counterclockwise with respect to a well-defined axis of rotation, and refine the research question based on the examination of data. [LO 4.D.1.2, SP 3.2, SP 4.1, SP 4.2, SP 5.1, SP 5.3]</p>	<p>Playground merry-go-round, timing devices, metersticks, force sensors or bathroom scales</p>	<p><b>Instructional Activity:</b></p> <p>Working in small groups, students use a playground merry-go-round to investigate how the application of an external torque affects the angular velocity and angular momentum of an object. Once students believe they have a qualitative idea of the relationship, they must collect and analyze data to support their conclusions quantitatively. A lab report is required from each group at the conclusion of the activity.</p>


**Guiding Questions:**

▼ What are the conditions necessary for two people with significant differences in mass to balance on a seesaw? ▼ What are the conditions necessary for static equilibrium? ▼ In what ways are rotational motion and linear motion related? ▼ What are the relationships among angular momentum, angular velocity, angular acceleration, rotational inertia, and torque?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque. [LO 5.E.1.1, SP 6.4, SP 7.2]</p> <p>Make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero. [LO 5.E.1.2, SP 2.1, SP 2.2]</p> <p>Describe or calculate the angular momentum and rotational inertia of a system in terms of the locations and velocities of objects that make up the system. Do qualitative reasoning with compound objects. Do calculations with a fixed set of extended objects and point masses. [LO 5.E.2.1, SP 2.2]</p> <p>Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semiquantitatively. [LO 4.A.1.1, SP 1.2, SP 1.4, SP 2.3, SP 6.4]</p>		<p><b>Instructional Activity:</b></p> <p>Peer teaching is utilized for the purpose of discovering the conservation of angular momentum and its relationship to rotational inertia. Students must determine why the rotational speed of an ice skater changes when the skater pulls his or her arms and legs in closer to the body. Students are encouraged to use the Internet to answer this question and to find other examples of conservation of angular momentum in action. Students then improve their understanding by sharing and discussing their research with their classmates. The concepts covered in this activity are then used to analyze the formation and shape of a typical spiral galaxy. For the final part of this activity, students research and show calculations on basic two-body systems found in our solar system.</p>
<p>Predict the behavior of rotational collision situations by the same processes that are used to analyze linear collision situations using an analogy between impulse and change of linear momentum and angular impulse and change of angular momentum. [LO 3.F.3.1, SP 6.4, SP 7.2]</p> <p>Describe a representation and use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system. [LO 4.D.1.1, SP 1.2, SP 1.4]</p>	<p>Popper toy, circular rotating platforms</p>	<p><b>Instructional Activity:</b></p> <p>Working in groups, students analyze and predict the motion of two adjacent merry-go-round analogs when a popper toy is used to exert a force from one onto the other in two situations:</p> <ol style="list-style-type: none"> <li>1. From the bottom of the left-hand merry-go-round to the bottom of the right-hand merry-go-round (viewed from above)</li> <li>2. Along a line tangent to the circles, from one onto the other, where the adjacent merry-go-rounds touch</li> </ol> <p>Students should easily determine the expected direction of rotation for both merry-go-rounds after the forces are applied, but they should find an apparent discrepant event in terms of conservation of angular momentum. Group members conduct research and collaborate to determine why the law of conservation of angular momentum is not broken. Each group provides a written explanation.</p>


**Guiding Questions:**

▼ What are the conditions necessary for two people with significant differences in mass to balance on a seesaw? ▼ What are the conditions necessary for static equilibrium? ▼ In what ways are rotational motion and linear motion related? ▼ What are the relationships among angular momentum, angular velocity, angular acceleration, rotational inertia, and torque?

Learning Objectives	Materials	Instructional Activities and Assessments
All learning objectives addressed in the unit are assessed on the summative assessment.		<p><b>Summative Assessment:</b></p> <p>Students are given approximately 30 multiple-choice questions with two or three free-response essay questions. Free-response prompts may include the following:</p> <ul style="list-style-type: none"> <li>• Explain the rotational kinematics involved in a car wreck.</li> <li>• Explain why many galaxies are spiral shaped and fairly planar.</li> <li>• Compare/contrast the rotational kinematics equations to their linear counterparts.</li> </ul>

*This summative assessment addresses all of the guiding questions for this unit.*

- Pendulum Challenge
- Springs in Oscillation
- What's in a Wave (Tank)?
- What's the Speed of Sound?



### Guiding Questions:

▼ What properties determine the motion of an object in simple harmonic motion? ▼ What exactly is a wave, and what are the various methods for creating one? ▼ What are the relationships between velocity, wavelength, and frequency of a wave? ▼ How do the relative motions of source and observer determine our perceptions of waves? ▼ What happens when two or more waves meet?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. [LO 3.B.3.1, SP 6.4, SP 7.2]</p> <p>Design a plan and collect data in order to ascertain the characteristics of the motion of a system undergoing oscillatory motion caused by a restoring force. [LO 3.B.3.2, SP 4.2]</p> <p>Analyze data to identify qualitative or quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion to use that data to determine the value of an unknown. [LO 3.B.3.3, SP 2.2, SP 5.1]</p> <p>Construct a qualitative and/or a quantitative explanation of oscillatory behavior given evidence of a restoring force. [LO 3.B.3.4, SP 2.2, SP 6.2]</p>	String, various small masses, metersticks, timing devices	<p><b>Instructional Activity:</b></p> <p>This activity is designed for students to discover the properties of a pendulum that determine its period. Each group is randomly assigned a period and is challenged to build a pendulum with exactly that period, using the provided materials. Next, the groups compare the pendulums they have made, making note of the period of each. Students then submit a report detailing what they believe to be the critical properties of a pendulum that determine its period.</p>
<p>Predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. [LO 3.B.3.1, SP 6.4, SP 7.2]</p> <p>Design a plan and collect data in order to ascertain the characteristics of the motion of a system undergoing oscillatory motion caused by a restoring force. [LO 3.B.3.2, SP 4.2]</p> <p>Analyze data to identify qualitative or quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion to use that data to determine the value of an unknown. [LO 3.B.3.3, SP 2.2, SP 5.1]</p> <p>Construct a qualitative and/or a quantitative explanation of oscillatory behavior given evidence of a restoring force. [LO 3.B.3.4, SP 2.2, SP 6.2]</p>	Set of springs, various masses, rulers or metersticks, timing devices	<p><b>Instructional Activity:</b></p> <p>Using various masses and other provided materials, students work in small groups to determine the spring constant of a spring in two different ways: with the masses stationary and with the masses oscillating in simple harmonic motion. Students submit a final report that includes a comparison of the two methods, including percent error. The report must also include a discussion of the similarities and differences between the variables involved in the two methods.</p>

# Simple Harmonic Motion, Waves, and Sound

(continued)



## Guiding Questions:

▼ What properties determine the motion of an object in simple harmonic motion? ▼ What exactly is a wave, and what are the various methods for creating one? ▼ What are the relationships between velocity, wavelength, and frequency of a wave? ▼ How do the relative motions of source and observer determine our perceptions of waves? ▼ What happens when two or more waves meet?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Use a visual representation to construct an explanation of the distinction between transverse and longitudinal waves by focusing on the vibration that generates the wave. [LO 6.A.1.1, SP 6.2]</p> <p>Describe representations of transverse and longitudinal waves. [LO 6.A.1.2, SP 1.2]</p> <p>Describe sound in terms of transfer of energy and momentum in a medium and relate the concepts to everyday examples. [LO 6.A.2.1, SP 6.4, SP 7.2]</p> <p>Use graphical representation of a periodic mechanical wave to determine the amplitude of the wave. [LO 6.A.3.1, SP 1.4]</p> <p>Explain and/or predict qualitatively how the energy carried by a sound wave relates to the amplitude of the wave, and/or apply this concept to a real-world example. [LO 6.A.4.1, SP 6.4]</p> <p>Use a graphical representation of a periodic mechanical wave (position versus time) to determine the period and frequency of the wave and describe how a change in the frequency would modify features of the representation. [LO 6.B.1.1, SP 1.4, SP 2.2]</p> <p>Use a visual representation of a periodic mechanical wave to determine wavelength of the wave. [LO 6.B.2.1, SP 1.4]</p>		<p><b>Instructional Activity:</b></p> <p>Students individually write a research paper exploring the basic properties and types of waves, as well as how they pertain to natural phenomena such as tsunamis and thunder. Students also create an interactive discovery tool that could be utilized to teach others about the relationships among period, frequency, velocity, wavelength, amplitude, and energy.</p>

*I use this activity to reinforce the basic concepts that most of my students encountered previously in a physical science course.*

# Simple Harmonic Motion, Waves, and Sound

(continued)

## Unit 6:



### Guiding Questions:

▼ What properties determine the motion of an object in simple harmonic motion? ▼ What exactly is a wave, and what are the various methods for creating one? ▼ What are the relationships between velocity, wavelength, and frequency of a wave? ▼ How do the relative motions of source and observer determine our perceptions of waves? ▼ What happens when two or more waves meet?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Design an experiment to determine the relationship between periodic wave speed, wavelength, and frequency and relate these concepts to everyday examples. [LO 6.B.4.1, SP 4.2, SP 5.1, SP 7.2]</p> <p>Use representations of individual pulses and construct representations to model the interaction of two wave pulses to analyze the superposition of two pulses. [LO 6.D.1.1, SP 1.1, SP 1.4]</p> <p>Design a suitable experiment and analyze data illustrating the superposition of mechanical waves (only for wave pulses or standing waves). [LO 6.D.1.2, SP 4.2, SP 5.1]</p> <p>Design a plan for collecting data to quantify the amplitude variations when two or more traveling waves or wave pulses interact in a given medium. [LO 6.D.1.3, SP 4.2]</p> <p>Analyze data or observations or evaluate evidence of the interaction of two or more traveling waves in one or two dimensions (i.e., circular wave fronts) to evaluate the variations in resultant amplitudes. [LO 6.D.2.1, SP 5.1]</p>	<p>Wave tank, water, various supplies for making waves</p> <p><b>Web</b> “Wave Interference”</p>	<p><b>Instructional Activity:</b></p> <p>Given a filled wave tank and a variety of supplies for making waves, students work in small groups to verify the relationships between wave velocity, wavelength, and frequency that they researched earlier in the unit. Then they investigate what happens when two or more waves meet in superposition. As an extension, students are encouraged to use the PhET simulation of a wave tank (which can be easier to manipulate) to verify or extend their assessment of what happens when two or more waves meet. Each group must utilize evidence from their investigations to support their conclusions and present their final analysis in a written report.</p>

# Simple Harmonic Motion, Waves, and Sound

(continued)



## Guiding Questions:

▼ What properties determine the motion of an object in simple harmonic motion? ▼ What exactly is a wave, and what are the various methods for creating one? ▼ What are the relationships between velocity, wavelength, and frequency of a wave? ▼ How do the relative motions of source and observer determine our perceptions of waves? ▼ What happens when two or more waves meet?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Refine a scientific question related to standing waves and design a detailed plan for the experiment that can be conducted to examine the phenomenon qualitatively or quantitatively. [LO 6.D.3.1, SP 2.1, SP 3.2, SP 4.2]</p> <p>Predict properties of standing waves that result from the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. [LO 6.D.3.2, SP 6.4]</p> <p>Plan data collection strategies, predict the outcome based on the relationship under test, perform data analysis, evaluate evidence compared to the prediction, explain any discrepancy and, if necessary, revise the relationship among variables responsible for establishing standing waves on a string or in a column of air. [LO 6.D.3.3, SP 3.2, SP 4.1, SP 5.1, SP 5.2, SP 5.3]</p> <p>Describe representations and models of situations in which standing waves result from the addition of incident and reflected waves confined to a region. [LO 6.D.3.4, SP 1.2]</p> <p>Challenge with evidence the claim that the wavelengths of standing waves are determined by the frequency of the source regardless of the size of the region. [LO 6.D.4.1, SP 1.5, SP 6.1]</p> <p>Calculate wavelengths and frequencies (if given wave speed) of standing waves based on boundary conditions and length of region within which the wave is confined, and calculate numerical values of wavelengths and frequencies. Examples should include musical instruments. [LO 6.D.4.2, SP 2.2]</p>	<p>Tuning forks, rulers or metersticks, graduated cylinders (1 or 2 L), glass resonance tubes, water</p>	<p><b>Instructional Activity:</b></p> <p>For students to discover the properties, characteristics, and usefulness of standing waves, they work in small groups to determine a method for calculating the speed of sound in the air of the classroom using only the provided materials. In addition to their determination of the speed of sound, they must explain in detail how the method works, how standing waves are responsible for the particular sound produced, what properties determine the character of the standing waves created (as represented in diagrams of the standing waves), and how these factors pertain to musical instruments.</p>
<p>Use a visual representation to explain how waves of slightly different frequency give rise to the phenomenon of beats. [LO 6.D.5.1, SP 1.2]</p>	<p><b>Web</b> "Interference of Waves of Unequal Frequencies (Formation of Beats)"</p>	<p><b>Instructional Activity:</b></p> <p>Given access to a simulation for production of beats, and after investigating wave superposition earlier in the unit, students work in small groups to construct a visual analysis (with written explanation as necessary for clarity) of what beats are and how they are produced.</p>

*It's also a good idea to have some frequency generators and/or tuning forks that are just slightly "off" to give students a real-world example. Students in band will already have a clear understanding!*

# Simple Harmonic Motion, Waves, and Sound

(continued)



## Guiding Questions:

▼ What properties determine the motion of an object in simple harmonic motion? ▼ What exactly is a wave, and what are the various methods for creating one? ▼ What are the relationships between velocity, wavelength, and frequency of a wave? ▼ How do the relative motions of source and observer determine our perceptions of waves? ▼ What happens when two or more waves meet?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Create or use a wave front diagram to demonstrate or interpret qualitatively the observed frequency of a wave, dependent upon relative motions of source and observer. [LO 6.B.5.1, SP 1.4]</p>		<p><b>Instructional Activity:</b></p> <p>Peer teaching is used to explain why the siren of an ambulance sounds different when it's coming toward you, as opposed to when it's moving away from you. Once presented with the question, pairs of students utilize Internet resources to discover the answer and find useful representations to share with the class. I intervene as necessary to keep class discussion on an appropriate track and avoid any misconceptions.</p>
<p>Analyze data to identify qualitative or quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion to use that data to determine the value of an unknown. [LO 3.B.3.3, SP 2.2, SP 5.1]</p> <p>Construct a qualitative and/or a quantitative explanation of oscillatory behavior given evidence of a restoring force. [LO 3.B.3.4, SP 2.2, SP 6.2]</p> <p>Predict properties of standing waves that result from the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. [LO 6.D.3.2, SP 6.4]</p> <p>Describe representations and models of situations in which standing waves result from the addition of incident and reflected waves confined to a region. [LO 6.D.3.4, SP 1.2]</p> <p>Challenge with evidence the claim that the wavelengths of standing waves are determined by the frequency of the source regardless of the size of the region. [LO 6.D.4.1, SP 1.5, SP 6.1]</p> <p>Calculate wavelengths and frequencies (if given wave speed) of standing waves based on boundary conditions and length of region within which the wave is confined, and calculate numerical values of wavelengths and frequencies. Examples should include musical instruments. [LO 6.D.4.2, SP 2.2]</p>		<p><b>Formative Assessment:</b></p> <p>To better gauge student understanding and as preparation for the summative assessment, I present students with a musical instrument challenge. Students must (individually or in collaboration with one other student) design and build a musical instrument (either with strings or open-ended tubing). They write a full report on the construction of the instrument and the physics behind its sound production and operation. Students also play a short tune for the class.</p>

*I read each report and provide written feedback.*


**Guiding Questions:**

▼ What properties determine the motion of an object in simple harmonic motion? ▼ What exactly is a wave, and what are the various methods for creating one? ▼ What are the relationships between velocity, wavelength, and frequency of a wave? ▼ How do the relative motions of source and observer determine our perceptions of waves? ▼ What happens when two or more waves meet?

Learning Objectives	Materials	Instructional Activities and Assessments
All learning objectives addressed in this unit are assessed on the summative assessment.		<b>Summative Assessment:</b> A multiple-choice test of approximately 30 questions is given.

*This summative assessment addresses all of the guiding questions for this unit.*

- Electroscope Lab
- Series Circuits
- Simple Parallel Circuits
- What's the Resistance?



### Guiding Questions:

▼ What is lightning, and why is it so dangerous? ▼ What are the fundamental carriers of electrical charge, and how may they be used to charge objects? ▼ How is gravitational force similar to electrical force, and in what ways are these forces very different? ▼ How are voltage, current, and resistance related in a series circuit? ▼ How are voltage, current, and resistance related in a simple parallel circuit?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Make claims about natural phenomena based on conservation of electric charge. [LO 1.B.1.1, SP 6.4]</p> <p>Make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. [LO 1.B.1.2, SP 6.4, SP 7.2]</p> <p>Challenge the claim that an electric charge smaller than the elementary charge has been isolated. [LO 1.B.3.1, SP 1.5, SP 6.1, SP 7.2]</p>	<p>Van de Graaff generator, stack of disposable aluminum pie plates, fur pelt, Styrofoam ball coated with metallic paint and suspended from a string, unfolded paper clip punched through a disposable aluminum pie plate</p>	<p><b>Instructional Activity:</b></p> <p>To get students thinking about charges, conservation of electrical charge, and the basis of natural phenomena involving static electricity, a Van de Graaff generator is utilized for basic demonstrations involving a variety of objects. A demonstration using a small paper clip “lightning rod” through a pie plate is used to show that lightning rods do more to prevent lightning than to attract and ground it. The demonstrations are followed by class discussion. Then students write a research paper about lightning and lightning safety. Papers should include discussion about the conservation of electric charge and various methods for separating charges, the elementary or fundamental particles of charge and their quantities/qualities, and how we know there can be no smaller carrier of charge.</p>
<p>Construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices. [LO 1.B.2.1, SP 6.2]</p>	<p>Electroscope, glass and plastic rods, small squares of various cloth, fur pelt</p>	<p><b>Instructional Activity:</b></p> <p>Working in small groups, students use rods, cloths of various materials, and an electroscope to draw conclusions about various kinds of interactions between electric charges, as well as to discover the charges imparted to different materials by rubbing with different cloths. Students must first be shown how the electroscope works and how to charge materials through rubbing, but then they may be left to discover different combinations and outcomes on their own. Students then produce a final written analysis of what they observed and the physical basis for it.</p>

*I traditionally use lightning as the subject of this introductory activity because students are usually interested in it, but any natural phenomenon involving static electricity would work fine.*

*My students can utilize the Internet for ideas and examples before submitting their final analysis, but most remember enough physical science from middle school to understand what they are observing.*


**Guiding Questions:**

▼ What is lightning, and why is it so dangerous? ▼ What are the fundamental carriers of electrical charge, and how may they be used to charge objects? ▼ How is gravitational force similar to electrical force, and in what ways are these forces very different? ▼ How are voltage, current, and resistance related in a series circuit? ▼ How are voltage, current, and resistance related in a simple parallel circuit?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges (interactions between collections of electric point charges are not covered in Physics 1 and instead are restricted to Physics 2). [LO 3.C.2.1, SP 2.2, SP 6.4]</p> <p>Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [LO 3.C.2.2, SP 7.2]</p>		<p><b>Instructional Activity:</b></p> <p>Students discover the similarities and differences between gravitational force and electrical force by writing a research paper concerning the forces at work within the nucleus of the atom. In the paper, students qualitatively compare and contrast the gravitational and electrical forces within the nucleus. They also present computational analysis using Coulomb's law and the universal law of gravitation to clearly demonstrate that the gravitational forces at work in the nucleus are so small as to be ignored. Additionally, they discuss why the repulsive forces between protons in the nucleus do not tear the nucleus apart.</p>

*This touches on subjects not specifically within the Physics 1 curriculum, but once students see the strength of the electrical repulsion between protons they tend to immediately want to know why the nucleus stays together.*


**Guiding Questions:**

▼ What is lightning, and why is it so dangerous? ▼ What are the fundamental carriers of electrical charge, and how may they be used to charge objects? ▼ How is gravitational force similar to electrical force, and in what ways are these forces very different? ▼ How are voltage, current, and resistance related in a series circuit? ▼ How are voltage, current, and resistance related in a simple parallel circuit?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule (<math>\Sigma\Delta V = 0</math>) in a circuit with only a battery and resistors either in series or in, at most, one pair of parallel branches. [LO 5.B.9.2, SP 4.2, SP 6.4, SP 7.2]</p> <p>Apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch. [LO 5.B.9.3, SP 2.2, SP 6.4, SP 7.2]</p> <p>Apply conservation of electric charge (Kirchhoff's junction rule) to the comparison of electric current in various segments of an electrical circuit with a single battery and resistors in series and in, at most, one parallel branch and predict how those values would change if configurations of the circuit are changed. [LO 5.C.3.1, SP 6.4, SP 7.2]</p> <p>Design an investigation of an electrical circuit with one or more resistors in which evidence of conservation of electric charge can be collected and analyzed. [LO 5.C.3.2, SP 4.1, SP 4.2, SP 5.1]</p> <p>Use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit. [LO 5.C.3.3, SP 1.4, SP 2.2]</p> <p>Construct or interpret a graph of the energy changes within an electrical circuit with only a single battery and resistors in series and/or in, at most, one parallel branch as an application of the conservation of energy (Kirchhoff's loop rule). [LO 5.B.9.1, SP 1.1, SP 1.4]</p>	<p>Circuit-building materials (including resistors, voltage sources, and wires) and multimeters</p>	<p><b>Instructional Activity:</b></p> <p>Students work in small groups to design and build a simple series circuit using a schematic diagram. Students should be able to explain how voltage, resistance, and current are related within their circuit. The final lab report should include analysis of the circuit as a whole, as well as analysis for each individual resistor included in the circuit.</p>


**Guiding Questions:**

▼ What is lightning, and why is it so dangerous? ▼ What are the fundamental carriers of electrical charge, and how may they be used to charge objects? ▼ How is gravitational force similar to electrical force, and in what ways are these forces very different? ▼ How are voltage, current, and resistance related in a series circuit? ▼ How are voltage, current, and resistance related in a simple parallel circuit?

Learning Objectives	Materials	Instructional Activities and Assessments
<p>Apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule (<math>\Sigma\Delta V = 0</math>) in a circuit with only a battery and resistors either in series or in, at most, one pair of parallel branches. [LO 5.B.9.2, SP 4.2, SP 6.4, SP 7.2]</p> <p>Apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch. [LO 5.B.9.3, SP 2.2, SP 6.4, SP 7.2]</p> <p>Apply conservation of electric charge (Kirchhoff's junction rule) to the comparison of electric current in various segments of an electrical circuit with a single battery and resistors in series and in, at most, one parallel branch and predict how those values would change if configurations of the circuit are changed. [LO 5.C.3.1, SP 6.4, SP 7.2]</p> <p>Design an investigation of an electrical circuit with one or more resistors in which evidence of conservation of electric charge can be collected and analyzed. [LO 5.C.3.2, SP 4.1, SP 4.2, SP 5.1]</p> <p>Use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit. [LO 5.C.3.3, SP 1.4, SP 2.2]</p> <p>Construct or interpret a graph of the energy changes within an electrical circuit with only a single battery and resistors in series and/or in, at most, one parallel branch as an application of the conservation of energy (Kirchhoff's loop rule). [LO 5.B.9.1, SP 1.1, SP 1.4]</p>	<p>Circuit-building materials (including resistors, voltage sources, and wires) and multimeters</p>	<p><b>Instructional Activity:</b></p> <p>Students work in small groups to construct a very basic parallel circuit (with only one pair of branches), using provided instructions. They then discover the relationships between voltage, current, and resistance for (1) the circuit as a whole, (2) each branch of the circuit, and (3) each individual resistor. Each group presents its findings in a lab report.</p>


**Guiding Questions:**

▼ What is lightning, and why is it so dangerous? ▼ What are the fundamental carriers of electrical charge, and how may they be used to charge objects? ▼ How is gravitational force similar to electrical force, and in what ways are these forces very different? ▼ How are voltage, current, and resistance related in a series circuit? ▼ How are voltage, current, and resistance related in a simple parallel circuit?

Learning Objectives	Materials	Instructional Activities and Assessments
Choose and justify the selection of data needed to determine resistivity for a given material. [LO 1.E.2.1, SP 4.1]	Circuit-building materials (including resistors, voltage sources, and wires), multimeters, and materials and/or resistors of unknown resistance	<b>Formative Assessment:</b> To determine if students have acquired the necessary understandings prior to the summative assessment, I provide each small group with a material of unknown resistance (or an actual resistor without observable markings), and I challenge students to determine the resistance. Any logical method that yields the correct result is acceptable. Each group must submit a formal report that fully supports its conclusion with experimental evidence, analysis, and discussion.
All learning objectives addressed in the unit are assessed on the summative assessment.	Circuit (with the main wiring and voltage source concealed by boxes), multimeter	<b>Summative Assessment:</b> Students take a two-part test, consisting of about 30 multiple-choice questions and a laboratory practical. The practical portion presents students with a circuit with the main wiring and voltage source concealed by boxes and only the resistors and a few potential junctions exposed (so that measurements may be taken with a multimeter). Students must take measurements they deem appropriate and then respond to questions and prompts such as the following: <ol style="list-style-type: none"> <li>1. Is this a series or parallel circuit?</li> <li>2. What is the voltage of the power source?</li> <li>3. Draw a schematic diagram of the whole circuit.</li> <li>4. Label the resistance of each resistor shown in your schematic diagram.</li> </ol>

*I provide feedback in written form, and I discuss the assignment with each group as needed.*

*This summative assessment addresses the following guiding questions:*

- What are the fundamental carriers of electrical charge, and how may they be used to charge objects?
- How is gravitational force similar to electrical force, and in what ways are these forces very different?
- How are voltage, current, and resistance related in a series circuit?
- How are voltage, current, and resistance related in a simple parallel circuit?



## General Resource

Walker, James. *Physics*. 4th ed. San Francisco: Pearson, 2010.

## Supplementary Resource

Hewitt, Paul. *Conceptual Physics*. 11th ed. San Francisco: Pearson, 2010.

## Unit 1 (Kinematics) Resources

“Addition of Forces (Vectors).” Chiu-king Ng. Online Physics Applets. Accessed August 20, 2012. <http://ngsir.netfirms.com/englishhtm/Vector.htm>.

“Kinematics of 1D Uniformly Accelerated Motion.” Chiu-king Ng. Online Physics Applets. Accessed August 20, 2012. <http://ngsir.netfirms.com/englishhtm/Kinematics.htm>.

“The Moving Man.” PhET. University of Colorado at Boulder. Accessed August 20, 2012. <http://phet.colorado.edu/en/simulation/moving-man>.

“Vector Addition.” PhET. University of Colorado at Boulder. Accessed August 20, 2012. <http://phet.colorado.edu/en/simulation/vector-addition>.

## Unit 2 (Newton’s Laws of Motion) Resources

*No unit-specific resources.*

## Unit 3 (Gravitation and Circular Motion) Resources

“Gravity Force Lab.” PhET. University of Colorado at Boulder. Accessed October 21, 2012. <http://phet.colorado.edu/en/simulation/gravity-force-lab>.

“My Solar System.” PhET. University of Colorado at Boulder. Accessed October 21, 2012. <http://phet.colorado.edu/en/simulation/my-solar-system>.

All links to online resources were verified before publication. In cases where links are no longer working, we suggest that you try to find the resource by doing a keyword Web search.

## Unit 4 (Work, Energy, Power, and Linear Momentum) Resources

*No unit-specific resources.*

## Supplementary Resources

Koser, John. “Laboratory Activity: Specific Heat by Change in Internal Energy of Silly Putty.” *The Physics Teacher* 49, no. 9 (2011): 574-575. <http://dx.doi.org/10.1119/1.3661107>.

## Unit 5 (Torque and Rotational Motion) Resources

“Balancing Act.” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/balancing-act>.

“Lady Bug: Angular Kinematics.” PhET. University of Colorado at Boulder. Accessed November 4, 2012. <http://phet.colorado.edu/en/contributions/view/3020>.

“Ladybug Revolution.” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/rotation>.

## Supplementary Resources

Van Hook, Stephen J. “Battle of the Merry-Go-Rounds: An Angular Momentum Demonstration.” *The Physics Teacher* 44, no. 5 (2006): 304-307. <http://dx.doi.org/10.1119/1.2195403>.

## Unit 6 (Simple Harmonic Motion, Waves, and Sound) Resources

“Interference of Waves of Unequal Frequencies (Formation of Beats).” Chiu-king Ng. Online Physics Applets. Accessed February 22, 2013. <http://ngsir.netfirms.com/englishhtm/Beats.htm>.

“Wave Interference.” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/wave-interference>.



### Supplementary Resources

“Masses & Springs.” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/mass-spring-lab>.

“Pendulum Lab.” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/pendulum-lab>.

“Sound.” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/sound>.

“Wave on a String.” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/wave-on-a-string>.

### Unit 7 (Electrostatics and Simple Electric Circuits) Resources

*No unit-specific resources.*

### Supplementary Resources

“Balloons and Static Electricity.” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/balloons>.

“Battery Voltage.” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/battery-voltage>.

“Charges and Fields.” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/charges-and-fields>.

“Circuit Construction Kit (DC only).” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc>.

“Electric Field of Dreams.” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/efield>.

“John Travoltage.” PhET. University of Colorado at Boulder. Accessed October 28, 2012. <http://phet.colorado.edu/en/simulation/travoltage>.