AP®

AP® Physics 1: Algebra-Based

Course Planning and Pacing Guide

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CollegeBoard

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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.

Contents

Instructional Setting

MAST Academy
Miami, Florida

School	MAST Academy is a nationally recognized, innovative magnet school of choice with a marine theme. This public high school is located on Virginia Key, a barrier island between the financial district of downtown Miami and the island village of Key Biscayne. Virginia Key has no residential inhabitants but is occupied by a host of marine and atmospheric science research facilities, including NOAA's Atlantic Oceanographic and Meteorological Laboratory and its Southeast Fisheries Science Center, as well as the University of Miami's Rosenstiel School of Marine and Atmospheric Science. Many of our students conduct scientific research at these facilities as part of a required internship component of their high school curriculum. In addition to the many science facilities, Virginia Key has several public beaches and private enterprises, which include restaurants, water sport facilities, and a marine amusement park.
Student population	The student population is approximately 850 students in grades 8 through 12. Approximately 34 percent qualify for free or reduced-price lunch. The school offers a wide variety of AP courses in all subject areas with 66 percent of the student population taking at least one AP examination. Students' racial/ethnic demographics include the following: • Hispanic: 50 percent • White non-Hispanic: 29 percent • African American: 17 percent • Asian/Pacific Islander: 4 percent One-hundred percent of students graduate from high school, and 99 percent go directly to college. Of those, 80 percent go directly to a four-year college or university, 18 percent go to a two-year college (with 75 percent later transferring to a four-year institution), and 2 percent attend a military academy. About 1 percent of students join enlisted military service each year. About 80 percent of students at MAST Academy elect to take regular, honors, and/or AP physics each year.

Instructional Setting

(continued)

Instructional time	The instructional year begins in mid-August and ends in early June. The school is on a block schedule with classes meeting for two 100-minute blocks and one 50-minute block each week. There are 180 instructional days per school year. Instead of cumulative midterms or final examinations, Miami-Dade County Public Schools administers End-of-Course Assessments standardized by the state of Florida. As of this writing, there is no End-of-Course Assessment for any of the physics courses.
Student preparation	Physics is an elective science course. Students typically take Honors Physics (AP Physics 1) during their junior year, after completing Honors Chemistry and (at least) Algebra 2.
Primary planning resources	Giancoli, Douglas C. *Physics: Principles with Applications.* 7th ed. New Jersey: Addison-Wesley, 2013. Hewitt, Paul G. *Conceptual Physics*. 11th ed. Boston: Addison-Wesley, 2011. Hieggelke, Curtis J., David P. Maloney, and Stephen E. Kanim. *Newtonian Tasks Inspired by Physics Education Research: nTIPERs*. Boston: Addison-Wesley, 2012. O'Kuma, Thomas L., David P. Maloney, and Curtis J. Hieggelke. *Ranking Task Exercises in Physics*. Boston: Addison-Wesley, 2004. "The AP Physics B Exam." The College Board. Accessed April 9, 2014. http://apcentral.collegeboard.com/apc/members/exam/exam_information/2007.html. Although the Physics 1 Exam differs from the Physics B Exam, some Physics B free-response questions are appropriate for student practice and can provide formative assessment data for the teacher.

Overview of the Course

Before becoming a secondary educator, I worked as a geophysicist. I quickly discovered that I had a great deal to learn about motivating and teaching teenagers, but that I also had much to offer in the way of engagement and bringing authentic research experience to my classroom. I have found that my real-world experiences both inspire and motivate my students. I make what I teach relevant to life experience, which provides the hook.

I use inquiry-based instruction with a student-centered and teacher-guided instructional approach that engages students. Students spend at least 25 percent of instructional time completing laboratory activities, which they record in a lab journal. The required contents of that lab journal include predictions, observations, data, data analysis, and conclusions. I also employ cooperative learning techniques and strive to help my students develop and strengthen their collaboration and teamwork skills. These are some of the most valuable tools I think I can provide students. I like to utilize peer tutoring and assessment techniques. For example, I train my students to apply College Board rubrics, acting as teachers by providing feedback on the quality of their peers' solutions to published AP free-response questions. My students learn a great deal from each other during whiteboarding sessions linked to their numerous laboratory activities; in these sessions I function merely as a guide.

Certainly mathematical competence helps a student maneuver through the complexities of physics. However, a solid conceptual understanding will often motivate students who have less of a foundation in mathematics to develop the requisite applied skills so that they can become more adept in problem solving, planning laboratory experiments, and performing their data analysis. I like to use Ranking Tasks in which students are presented with physical situations and expected to make outcome comparisons based on varying physical quantities. These activities help develop the conceptual understanding of my students. To make sure students understand the material before I move on, I use what I call Quick Quizzes, usually at the opening of each class. They are ungraded so that my students can take risks and show their knowledge without the high stakes of an exam. They serve as a motivation for students to keep up with course material and pacing, and they provide me feedback so I can make sure key concepts are understood.

I am constantly self-reflecting. I evaluate the results of my assessments, which often leads to reteaching topics that prove particularly difficult for my students yet are foundational concepts necessary for deeper student understanding. This requires that I teach ideas in a variety of ways. I know my students have different learning styles and what might work well for one does not necessarily work at all for others. Through small group work (two to four students) culminating in white-boarding to the whole class, I help my students develop valuable skills such as verbal expression, spatial comprehension, composition, and visual communication. Through the many lab reports my class requires, my students also develop their writing skills. Beyond typical summative assessments, I include a variety of assessment types — including individual and group activities — that provide students with diverse opportunities to show that they have mastered the material.

I foster an environment of mutual respect. I want my students to feel validated and empowered so that they truly believe their ideas, input, needs and opinions are valued. I believe this approach generally produces buy-in and minimizes potential behavioral problems.

Unit 1: Kinematics

Laboratory Investigations:

- Determining Acceleration Due to Gravity
- Relative Motion
- Predicting Projectile Motion Range

Estimated Time:
4 weeks

Guiding Questions: ▼ How do we formulate a descriptive understanding of motion (within confines of constant acceleration)? ▼ How is motion described with respect to a different frame of reference? ▼ How are vector quantities separated into component parts so that the motion of an object can be analyzed as two separate motions?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	Giancoli, Chapter 1: "Introduction"	**Instructional Activity:** Students engage in a few short activities that review prior knowledge of concepts such as conversion factors, the metric system and use of SI prefixes, scientific notation, fundamentals of algebra, and the translation of word problems into mathematical formulas.
		Formative Assessment: Students are given a short assessment to determine if they have acquired the mathematical skills requisite to proceed successfully with the study of quantitative physics. These skills include converting and estimating SI units, expressing answers correctly with respect to significant digits, and efficiently using scientific notation.
	Fullerton, "Graphical Analysis of Motion," pp. 41–48 **Web** "Interpreting Distance–Time Graphs" "Kinematics Graph Activity"	**Instructional Activity:** In this guided-inquiry activity, particle or ticker-tape diagrams are used to visually guide students' understanding of motion. Then, in groups of two to four, students plan and conduct a graphical analysis of motion to determine relationships between displacement–time (slope is velocity) and velocity–time (slope is acceleration), and to determine that the area under the curve for a velocity–time graph is displacement.
		Formative Assessment: Individually, students interpret and design their own graphing stories and then present and discuss their work. Requirements for stories include constructing and interpreting graphical representations of position, velocity, and acceleration and making connections between slope and velocity (for example, showing that the vertical intercept of a v–t plot is initial velocity).

Students of physics need basic mathematics skills or certainly a willingness to work towards gaining them. You will likely have to spend some class time getting your students up to speed on some background topics.

By assessing the students' prior knowledge, I can better predict how much instructional time I may need to allow for future topics and concepts. I provide written feedback directly to students so that they can self-identify areas where further practice and review are necessary. If needed, I conduct a few brief lectures to guide further student self-study.

I evaluate the final peer-critiqued, student-revised story. If there are consistent common mistakes, I reteach the relevant topics with a focus on clearing up those specific misconceptions. I also give individual feedback to students to ensure that misconceptions and any of their lingering questions are addressed.

Guiding Questions: ▼ How do we formulate a descriptive understanding of motion (within confines of constant acceleration)? ▼ How is motion described with respect to a different frame of reference? ▼ How are vector quantities separated into component parts so that the motion of an object can be analyzed as two separate motions?

Learning Objectives	Materials	Instructional Activities and Assessments
Design an experimental investigation of the motion of an object. [LO 3.A.1.2, SP 4.2] 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]	**Web** "Describing Motion with Diagrams" "The Moving Man" **Video** "Ticker Tape Demo_2.m4v" **Supplies** Ticker tape timer, ticker tape with carbon disk, power supply	**Instructional Activity:** This student-directed, guided-inquiry activity introduces students to the process of describing motion graphically with diagrams. How motion is measured and analyzed using ticker tape methods is explained using a whole-class demonstration and a video. Students then work individually with web simulations to analyze one-dimensional motion data.
	Supplies Ticker tape timers, ticker tapes with carbon disks, power supplies, scissors, range of 50–500 gram masses, metersticks	**Instructional Activity:** In the Determining Acceleration Due to Gravity Lab, students working in groups of two to three use a ticker tape to design an experiment to measure distance, speed, and acceleration to determine free-fall acceleration of objects with various mass due to gravity, *g*. This is a guided-inquiry investigation.
		Formative Assessment: Individually, students prepare a full lab report from their free-fall investigation. The student report should include measuring displacement as a function of time. In their reports students are required to graph their results and apply curve-fitting to determine the value of free-fall acceleration, *g*. They are also required to discuss the mass independence based on the evidence collected during their investigation.

I provide individual feedback to students, focusing in particular on student understanding of graphical analysis of experimental data.

Guiding Questions: ▼ How do we formulate a descriptive understanding of motion (within confines of constant acceleration)? ▼ How is motion described with respect to a different frame of reference? ▼ How are vector quantities separated into component parts so that the motion of an object can be analyzed as two separate motions?

Learning Objectives	Materials	Instructional Activities and Assessments
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]		**Formative Assessment:** Students take an assessment consisting of both multiple-choice questions and open-ended problem-solving questions that involve the use of equations of motion. This assessment indicates students' level of mastery in the application and use of these fundamental equations of motion for constant acceleration.
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] 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]	Fullerton, Questions 2.15–2.24 Giancoli, Chapter 3: "Kinematics in Two Dimensions; Vectors," Sections 3-1 to 3-4	**Instructional Activity:** Students engage in exercises involving scaled diagrams to represent and manipulate vectors and determine angles, if given components. Students also demonstrate vector algebra both graphically and by using component methods. Examples of displacement, velocity, and acceleration are used.
	Video *Frames of Reference* **Supplies** Two variable-speed battery-operated toy vehicles, metersticks, tape, stopwatches	**Instructional Activity:** In the Relative Motion Lab, students working in groups utilize two variable-speed, battery-operated toy vehicles and design an experiment to test how velocities add in two dimensions.
	Giancoli, Chapter 3: "Kinematics in Two Dimensions; Vectors," Section 3-8	**Formative Assessment:** Students complete exam-type problems designed to assess their ability to determine vector results, both graphically and using components of adding/subtracting vectors, and the result from multiplication by a scalar quantity. Students must also be able to differentiate between scalar and vector quantities and resolve a vector into components both graphically and algebraically.

These skills form an essential foundation for many future units in AP Physics 1. Therefore, detailed teacher feedback is critical at this early point in the course. Depending on the level of mastery of specific types of problems and learning objectives demonstrated by students on this assessment, I may modify my instruction and/or reinforce particular science practices, learning objectives, and enduring understandings.

Prior to engaging in this activity, students should review and learn to apply the basic sine, cosine, and tangent trigonometric relations; the Pythagorean theorem; and a variety of author-dependent vector notations.

This guided-inquiry lab allows students to demonstrate and build upon the knowledge they gained in the previous lesson on vectors and 2D kinematics. I like to preface the investigation with the engaging video Frames of Reference*, which demonstrates relative motion.*

This assessment helps me gauge the students' understanding of using vectors and determine the amount of further reinforcement that is needed in the upcoming projectile motion activities. I provide feedback using comments on student work and assign additional problems to reinforce areas of weakness, where needed.

Guiding Questions: ▼ How do we formulate a descriptive understanding of motion (within confines of constant acceleration)? ▼ How is motion described with respect to a different frame of reference? ▼ How are vector quantities separated into component parts so that the motion of an object can be analyzed as two separate motions?

Learning Objectives	Materials	Instructional Activities and Assessments
Design an experimental investigation of the motion of an object. [LO 3.A.1.2, SP 4.2] 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]	**Web** "Projectile Motion" "4: The Motion of Projectiles" **Supplies** Small steel balls (or similar objects with minimal air resistance)	**Instructional Activity:** This activity includes a teacher-directed class demonstration in which two similar objects are dropped from the same height, one from rest and one launched with horizontal speed. I have students predict which object will hit the ground first; they then observe that both hit the ground at the same time. Following this demonstration is a facilitated discussion on the separation of horizontal and vertical motion with web and video images.
	Web "Projectile Motion"	**Instructional Activity:** In this structured-inquiry activity, students working individually use an online simulation to explore the motion of projectiles, varying initial speed and angle and viewing the resulting range, with and without air resistance.
	Supplies Spring-loaded projectile launchers, steel balls, metersticks, protractors, "bull's eye" targets, carbon paper (to mark landing spot)	**Instructional Activity:** In the Predicting Projectile Motion Range Lab, groups of two to four students design and test range, height, and time of flight for projectiles with differing initial conditions, varying initial velocity (speed and angle), initial height, and projectile mass. This is a guided-inquiry investigation.
		Formative Assessment: Working individually, students must determine where to place a target on the floor so that it is hit by a projectile launched from a given height and angle set by me. Students must recognize the independence of the vertical and horizontal motions of the projectile in order to be successful.
All of the learning objectives in the unit are assessed.		**Summative Assessment:** Students take an assessment consisting of ranking tasks, multiple-choice questions, and open-ended problem-solving questions involving equations of motion, applications of vectors, relative motion, and projectile motion.

You may also consider using smartphone apps that allow students to record and email video and/or data for computer upload for further analysis. Students are often excited to work with videos that they have made using personal tech equipment.

I make sure that I look for potential student pitfalls such as using the range equation when Δy is not actually equal to zero.

I walk around during the activity and provide direct feedback to students. Students who miss the target present all their calculations to me so I can help them troubleshoot.

This assessment addresses all of the guiding questions for the unit.

Newton's Laws of Motion

Laboratory Investigations:

- Newton's Second Law
- Atwood Machine
- Friction
- Inclined Planes

Estimated Time:

4 weeks

Guiding Questions: ▼ How can the state of an object's motion be changed? ▼ What is the connection between mass and weight? ▼ How is friction included in the mathematical description of motion? ▼ How are static and dynamic equilibrium different?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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]	**Supplies** Tablecloth, smooth table, various objects (e.g., textbook, trophy, lunchbox, calculator) **Video** "Newton's Laws – Tablecloth Trick #1"	**Instructional Activity:** As an introduction to student discussion, I demonstrate Newton's first law by quickly pulling a tablecloth out from under stationary objects (or by showing a video of this trick). The class then engages in a facilitated discussion on inertia, referencing real-life examples and applications including sliding hockey pucks or dry ice, space probes, and seat belts and head rests in cars.
		Formative Assessment: Students design and create videos of examples that model Newton's first law. They then share their videos with the class.
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]	**Supplies** Air track systems with gliders, photogate timers with accessory photogates, pulleys, mounting clamps, masses	**Instructional Activity:** The Newton's Second Law Lab has two parts. Part I: Students observe a teacher demonstration to gain an understanding of how to use an air track as a frictionless surface and how to use photogates, timers, and pulley systems. Part II: In this guided-inquiry activity, students work in groups to design an experiment to apply constant force while varying mass and measuring the resulting accelerations. They then use a constant mass while varying applied force, again measuring the resulting accelerations.
	Giancoli, Chapter 4: "Dynamics: Newton's Laws of Motion" Hieggelke, Maloney, and Kanim, Questions 31, 34, 52–53, 63–64, 76, 78, 87	**Instructional Activity:** Students work to solve changing representations problems — similar to free-response questions on the AP Physics Exam — that require the use of Newton's second law. These include problems involving friction, inclined planes, and pulleys.

The students and I provide feedback and critiques of each video.

Rather than providing Newton's second law to students, I use the modeling approach so students develop mathematical models from graphs of acceleration versus force and acceleration versus mass through guided-inquiry. Based on their laboratory investigations, students discover and determine that F = ma.

I provide written feedback on students' solutions. Based on student performance, I may do a few extra problems with the class to clear up misconceptions.

Newton's Laws of Motion
(continued)

Guiding Questions: ▼ How can the state of an object's motion be changed? ▼ What is the connection between mass and weight? ▼ How is friction included in the mathematical description of motion? ▼ How are static and dynamic equilibrium different?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	**Web** "Motion in 2D" "2D Motion"	**Formative Assessment:** Students individually use the PhET simulation "Motion in 2D" to solve problems from the accompanying worksheet by Patrick Foley.
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] Describe a force as an interaction between two objects and identify both objects for any force. [LO 3.A.3.3, SP 1.4] 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]	**Supplies** Photogate timers with accessory photogates, pulleys, mounting clamps, hanging mass sets, light strings or cords	**Instructional Activity:** In the Atwood Machine Lab, students in groups of two to three connect two different masses with a string, hang the string over a pulley, and then determine the acceleration of the Atwood machine system. This is a guided-inquiry activity.
		Formative Assessment: Each student completes a formal lab report of the Atwood Machine Lab. The lab report should include the following: several trials with varying masses and resulting acceleration, final velocities of each system determined from power or linear regression analysis, and appropriate statistical information.
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] 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] 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] 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] ***(learning objectives continue)***	**Web** "Free Particle Model Worksheet 1b: Force Diagrams and Component Forces"	**Instructional Activity:** This activity introduces students to contact and normal forces and to the use of free-body diagrams (FBDs) to solve statics and dynamics problems. Providing students with practice problems helps with their construction of FBDs for different scenarios of statics, tension, and components both on paper and in the lab.

Students' answers to these questions provide insight into their mastery of the concepts. The level of student understanding helps me decide if additional review is needed before moving on to the next investigation.

I preface this investigation with a discussion on connected masses and introduce some of the fundamental assumptions for problem solving in physics, including the notion of a frictionless pulley and massless, stretchless strings. This is also an appropriate time to review or teach methods of statistical analysis and to introduce students to statistical software and the use of a computer interface that enables upload of data.

I pay particular attention to measurement, error analysis, and methods of statistical analysis in this report and warn my students prior to the assignment that this will be my emphasis. Most of my feedback is focused on these issues.

Guiding Questions: ▼ How can the state of an object's motion be changed? ▼ What is the connection between mass and weight? ▼ How is friction included in the mathematical description of motion? ▼ How are static and dynamic equilibrium different?

Learning Objectives	Materials	Instructional Activities and Assessments
(continued) 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] Make claims about various contact forces between objects based on the microscopic cause of those forces. [LO 3.C.4.1, SP 6.1]		
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] 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]		**Formative Assessment:** Students take an assessment consisting of questions, similar to those in the previous activity, that pose FBD scenarios. Students are to determine acceleration or unknown mass given various situations.
Challenge a claim that an object can exert a force on itself. [LO 3.A.3.2, SP 6.1] 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]	**Supplies** Wooden or metal boards covered with various materials (e.g., brown paper bag, plastic, cloth), objects to pull (approximately 2" × 4" × 6"), spring scales, string, masses	**Instructional Activity:** In the Friction Lab, students in groups of two to four explore and determine mu between various objects on boards covered with different materials and use spring scales to determine the threshold force needed to begin motion. Students vary mass and use differing base areas to show that mu is independent of contact area. This is a guided-inquiry activity.
		Formative Assessment: Students write individual lab reports about the previous activity to demonstrate their overall understanding of friction.
Apply $\vec{F} = m\vec{g}$ to calculate the gravitational force on an object with mass *m* in a gravitational field of strength *g* 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] Describe a force as an interaction between two objects and identify both objects for any force. [LO 3.A.3.3, SP 1.4] 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]	Giancoli, Chapter 4: "Dynamics: Newton's Laws of Motion," Section 4-6, Example 4-8, Questions 10 and 15–16 **Video** "Apparent Weight and Weightlessness"	**Instructional Activity:** This activity includes a video introduction of weight and its distinction from mass. Students also explore how weight varies in an accelerating reference frame and/or in varying gravitational fields. Textbook examples and associated problem-solving exercises are used to reinforce understanding (properties of weight versus mass).

I use the results of this assessment to gauge students' ability to analyze forces; this helps me determine whether any reteaching is needed.

I discuss with students the concepts of static versus kinetic friction and independence of contact area between two surfaces.

The Friction Lab is straightforward; therefore, this should be a simple write-up. I have students focus their attention on error analysis. Student performance on this assignment helps me determine the level of understanding of error analysis so that I can assign additional practice and/or reteach the material as needed.

I especially like to use the example of weighing oneself in an accelerating elevator, as students have had, and therefore can relate to, this experience.

Guiding Questions: ▼ How can the state of an object's motion be changed? ▼ What is the connection between mass and weight? ▼ How is friction included in the mathematical description of motion? ▼ How are static and dynamic equilibrium different?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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]	**Supplies** Wooden or metal boards covered with various materials (like those used in the Friction Lab), objects to slide down ramps, protractors	**Instructional Activity:** In the Inclined Planes Lab, students in groups of two to four determine mu from slope angle needed to initiate motion of mass (angle of repose). This is an extension of the earlier Friction Lab so students may use the materials of known mu now on inclined planes. This is a guided-inquiry activity.
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]	**Supplies** Pair of spring scales or force sensors **Web** Halloun and Hestenes, "Common Sense Concepts about Motion"	**Instructional Activity:** In this guided-inquiry activity, I first demonstrate action–reaction pairs and discuss them with students. Examples include pushing on a wall (the wall pushes back) or kicking a ball. Students then explore different ways in which this phenomenon can be represented. For example, they hook spring scales or force probes together and pull, push, or hold one still to demonstrate how in all cases the forces will be equal and opposite.
	Web Web page for the Force Concept Inventory	**Formative Assessment:** Students take a quiz with short-answer and multiple-choice questions similar to those in the Force Concept Inventory.
All of the learning objectives in the unit are assessed.		**Summative Assessment:** Students take an assessment consisting of a variety of problems chosen so that all guiding questions and learning objectives from this unit are addressed. This assessment includes free-response questions similar to those that appear on the AP Exam. These questions focus on Newton's second law, incorporating topics such as friction, pulleys, inclines, and apparent weight of moving objects.

Accurate angle measurement is often difficult for students. I guide this process by circulating through the room and conducting demonstrations for a few groups at a time.

Students come with many preconceived misconceptions related to Newton's third law. I recommend that teachers read "Common Sense Concepts about Motion," which is helpful for developing a systematic and complete taxonomy of the typical common-sense misconceptions; this can aid in producing a more efficient instructional design. Focus on forces coming in pairs and on the concepts that paired forces are equal in magnitude and opposite in direction and act on separate bodies.

I provide feedback to students through comments on their work. Student performance on this assessment allows me to reflect on the instructional strategies I have used and their effectiveness.

This assessment addresses all of the guiding questions for the unit.

Unit 3: Work, Energy, and Power

Laboratory Investigations:

- It's All Uphill
- Hooke's Law and Work on a Spring
- Inclined Plane Physics Challenge

Estimated Time: *4 weeks*

Guiding Questions: ▼ How does energy transfer explain change? ▼ How can conservation of energy be used to predict an object's motion?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] 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] 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] 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] 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]	**Video** "11. Work - Kinetic Energy - Potential Energy - Conservative Forces - Conservation of Mechanical …" **Web** "Calculating the Amount of Work Done by Forces"	**Instructional Activity:** This activity uses a video to introduce students to the concepts and definitions of work and kinetic energy. After watching the video, students engage in a teacher-facilitated discussion about the video's key concepts and then complete example problems on the Physics Classroom website to strengthen their understanding of concepts and practice applying the necessary mathematical routines.
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] 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] ***(learning objectives continue)***	Giancoli, Chapter 6: "Work and Energy" Hieggelke, Maloney, and Kanim	**Formative Assessment:** Working individually, students respond to linked multiple-choice tasks, standard multiple-choice questions, and open-ended problem-solving questions that incorporate the definitions of work and energy to assess student understanding.

I like this video because it shows applications of trigonometric functions used to calculate work done by forces not parallel to displacement.

I provide written notes on students' work to correct misconceptions and guide students to a better understanding of the problem-solving process. Based on class results, I may provide additional instruction prior to advancing to the next activity.

Guiding Questions: ▼ How does energy transfer explain change? ▼ How can conservation of energy be used to predict an object's motion?

Learning Objectives	Materials	Instructional Activities and Assessments
(continued) 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] 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] 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] 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]		
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] 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]	**Supplies** Block of wood, spring-loaded force meter, table	**Instructional Activity:** In this activity, I introduce students to work and potential energy concepts using examples and demonstrations, which include showing how a nonzero force is needed to pull a block of wood along a table at a constant rate (zero acceleration) and how the work that is done is used to overcome friction.

During the demonstrations, I query students as to how they could determine the coefficient of friction, which requires reflection back to the Unit 2 Friction Lab. I guide students to make the connection between friction and the work done by the force applied to move an object at a constant or reduced rate.

Guiding Questions: ▼ How does energy transfer explain change? ▼ How can conservation of energy be used to predict an object's motion?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] 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] 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] 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] 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]	**Supplies** Boards for inclines, carts, force probes, metersticks, protractors, mass balances, pulleys, hanging weights	**Instructional Activity:** In the It's All Uphill Lab, students working individually move a cart uphill first at a constant rate at varying angles to determine the weight component relationship. Students then design and implement experimental procedures for measuring the acceleration at particular angles and determining the mass of the cart (i.e., varying the force). Students also explore how to use a pulley to create the applied force by attaching various hanging weights. This activity is also used to introduce potential energy as work done to pull a cart uphill. This is a guided-inquiry activity.

Guiding Questions: ▼ How does energy transfer explain change? ▼ How can conservation of energy be used to predict an object's motion?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] Describe and make predictions about the internal energy of systems. [LO 5.B.4.1, SP 6.4, SP 7.2] 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] 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)	Giancoli, Chapter 6: "Work and Energy"	**Formative Assessment:** Students complete individual reports about the previous lab. Reports should emphasize the use of calculations to justify friction as a possible explanation for discrepancies in expected versus measured results. Reports should also include a detailed free-body diagram for each investigation.
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] 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] 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]	**Supplies** Various springs of differing spring constants, various masses	**Instructional Activity:** This activity introduces Hooke's law and elastic potential energy. I use a brief teacher-directed pre-lab demonstration involving springs of varying spring constants. The concept development begins with a horizontally lying spring and the addition of gravitational potential for vertically hanging springs. Students are expected to make measurements, discuss their observations, take notes on results, and pose questions based on these results and observations for use in their upcoming lab activity.

I assign FBD problems from Giancoli with the same geometric setup as the lab along with the lab report assignment.

In my written feedback on the reports, I generally include comments focusing on any misunderstandings of geometric or trigonometric applications to FBDs.

I like to provide lots of examples of stretchy objects that do not obey Hooke's law. I really stress observing signs of the restoring force on the objects.

Guiding Questions: ▼ How does energy transfer explain change? ▼ How can conservation of energy be used to predict an object's motion?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	**Supplies** Various springs of differing spring constants, calibrated masses (or scale), metersticks	**Instructional Activity:** In the Hooke's Law and Work on a Spring Lab, students individually design and implement an investigation to determine the spring constant for a given spring and verify if the spring obeys Hooke's law. They must also determine the relationship to the amount of work done to stretch (or compress) the spring. This is a guided-inquiry activity.
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]	Giancoli, Chapter 6: "Energy and Work"	**Formative Assessment:** Students are assigned multiple-choice questions and open-ended problems covering basic Hooke's law calculations and concepts. Some of these questions focus on experimental design tasks that require linearization and error analysis.
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]		**Instructional Activity:** This activity introduces students to the law of conservation of energy. A teacher-led discussion emphasizes potential frictional effects, which can be accounted for by comparing measurable energies in a system. To further develop this concept, students explore and use energy bar chart illustrations as a visual for demonstrating semi-quantitative partitioning of energies in a system.
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]	**Supplies** Air tracks, two photogates, timers, air track carts, masses, string, pulleys	**Instructional Activity:** Students work in groups of two to four to complete the Inclined Plane Physics Challenge Lab, a guided-inquiry activity. In this lab, each group designs and implements an investigation to determine how much mass to hang on a pulley so that a cart is pulled up an inclined air track and accelerates between photogates set a fixed distance apart in a given time. Different cart masses and different theta are provided. Students must turn in detailed calculations at the time of mass loading. The timing determines the grade on this assignment, which can be adjusted if calculations are suitably detailed (and correct).

You can conduct this as a simple classroom activity or as a more in-depth investigation requiring a full lab report as a formative assessment, depending on your needs and the time available.

I provide written comments in response to students' work on the open-ended problems. Student performance on this assessment helps me gauge understanding and determine how much additional review might be necessary to ensure success with the upcoming topic, the law of conservation of energy.

This is one of the most fundamental principles of mechanics and it is important to stress the enormous implications as to the symmetry of nature.

Guiding Questions: ▼ How does energy transfer explain change? ▼ How can conservation of energy be used to predict an object's motion?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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]	**Supplies** Timers, protractors, tape measures, calculators, accelerometers, g-force meters	**Formative Assessment:** This assessment involves a field trip to an amusement park with roller coasters. To prepare for the trip, students engage in activities that help them connect physics principles to ride-specific objectives and learn to use equipment including accelerometers and g-force meters to capture data. At the amusement park, students in groups of two to four make measurements and necessary calculations for a preassigned ride. After the field trip, student groups present their findings and results to the class.
All of the learning objectives in the unit are assessed.		**Summative Assessment:** Students take an exam consisting of linked multiple-choice and bar chart tasks, standard multiple-choice questions, and problem-solving questions. The exam assesses mastery in the application and use of fundamental equations of work, energy, power, and elasticity.

This activity helps students make connections between work and energy and enables them to provide explanations for the sensations they experience on a roller coaster. Teacher-guided peer feedback is given during group presentations.

Many amusement parks host "Physics Days," which are ideal for class trips such as this one.

This assessment addresses all of the guiding questions for the unit.

Unit 4: Linear Momentum

Laboratory Investigations:

- Collision — Impulse and Momentum
- Conservation of Momentum in Collisions and Explosions
- Two-Dimensional Collisions

Estimated Time:

4 weeks

Guiding Questions: ▼ What effect does mass have on the result of a collision? ▼ Where does the energy go in a collision?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] 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] 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]	**Video** "Momentum"	**Instructional Activity:** This activity begins with a video introduction of concepts related to impulse and momentum and their relationship to force. Students then participate in a teacher-directed discussion incorporating the physics of collisions to emphasize and clarify understanding of momentum and impulse.
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] 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] 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] 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]	Comer and Griffith, "Collision – Impulse & Momentum" **Supplies** Air tracks with bumpers, collision carts, force sensors, motion sensors, timers, mass balances, levels	**Instructional Activity:** In the Collision – Impulse and Momentum Lab, groups of two to four students design and implement an experiment to investigate the relationship between force on an object in a collision and time duration of the collision. Students use a motion sensor to measure the velocity change of a collision cart as it collides with a stationary bumper. Students also measure cart velocity before and after the collision and compare their measurements to the change in momentum based on that calculated by force sensor readings as a function of time. This is a guided-inquiry activity.
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]		**Formative Assessment:** Individually, students are required to prepare a full lab report detailing the measurements and analysis of the previous investigation. Understanding of area under a curve is essential and should be represented in these reports.

Force sensors may need to be calibrated. Make sure the air track is on a horizontal. Calculus is not necessary for this activity as area under the F–t graph can be estimated geometrically. During this lab, I provide continuous assistance, safety monitoring, and feedback during data collection and analysis.

I provide feedback in the form of comments and remediation exercises as needed. This helps to prepare students for the next set of momentum labs and activities.

Guiding Questions: ▼ What effect does mass have on the result of a collision? ▼ Where does the energy go in a collision?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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. [LO 5.D.1.2, SP 2.2, SP 3.2, SP 5.1, SP 5.3] 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] 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] 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] 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] 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 with the system. [LO 5.D.3.1, SP 6.4]	**Web** "Collision Lab"	**Instructional Activity:** In this activity, students are introduced to elastic and inelastic collisions in 1D and at angles. Throughout the activity, the vector nature of momentum and its conservation, including its application to explosions, are stressed. Students use the web simulation of an air hockey table to investigate collisions in 1D and in 2D. They also run the simulation with multiple discs and varying masses and initial conditions.

Students are often puzzled that they can't simply apply the law of conservation of energy to solve collision problems. It is important to remind them that some energy is invariably lost to the collision.

Guiding Questions: ▼ What effect does mass have on the result of a collision? ▼ Where does the energy go in a collision?

Learning Objectives	Materials	Instructional Activities and Assessments
Analyze data to 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] 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, SP 5.1, SP 5.3, SP 6.4]	**Supplies** Air tracks, carts, force sensors, motion sensors, timers, video cameras (30 fps or faster) or smartphones, springs	**Instructional Activity:** In the Conservation of Momentum in Collisions and Explosions Lab, students individually conduct frame-by-frame time analysis of motion from video clips of elastic and (perfectly) inelastic collisions and of explosions in order to verify the law of conservation of momentum. Standard smartphones take video with adequate frames per second for this activity. An explosion is accomplished by connecting two cars by a compressed spring. This is a guided-inquiry activity.
		Formative Assessment: Along with completing some bar chart tasks, students individually prepare and submit lab reports for the previous investigation. The reports should include detailed lab and analysis procedures and tabulation of before- and after-collision data.
	Giancoli, Chapter 7: "Linear Momentum," Sections 7-1 to 7-6 Hieggelke, Maloney, and Kanim	**Formative Assessment:** Students take an assessment consisting of bar chart tasks, standard multiple-choice questions, and open-ended problem-solving questions. The assessment allows students to demonstrate their understanding of impulse and one-dimensional conservation of momentum problems.

I provide written feedback directly to students via comments, focusing in particular on collision vector analysis. Lab reports help me gauge whether students are ready to move forward with two-dimensional momentum or whether some aspects of collision need instructional reiteration.

I provide comments and redirection with calculations to students directly on their papers. As with the previous formative assessment, this task helps me determine if the students are ready to move on to two-dimensional momentum. The bar chart tasks help me assess student understanding of energy partitioning in collisions.

Guiding Questions: ▼ What effect does mass have on the result of a collision? ▼ Where does the energy go in a collision?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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]	**Supplies** Air tables, air pucks, video cameras (30 fps or faster) or smartphones mounted about 2 m above air tables **Web** "Colliding Pucks on an Air Table"	**Instructional Activity:** In the Two-Dimensional Collisions Lab, groups of two to three students film the collision of two pucks on an air table. They then conduct frame-by-frame time analysis of motion from video clips of the two-dimensional elastic collision in order to verify that momentum is conserved.
	Giancoli, Chapter 7: "Linear Momentum," Section 7-7	**Formative Assessment:** Students complete individual reports about the previous lab, along with additional exercises involving two-dimensional conservation of vector momenta problems.
All of the learning objectives in the unit are assessed.		**Summative Assessment:** Students complete an assessment consisting of multiple-choice questions and open-ended problem-solving questions addressing the concepts covered in this unit. The assessment includes one- and two-dimensional conservation of momentum standard and lab-based problems.

You may need to review the application of vector components prior to this lab. Smartphones can be used in place of video cameras, or as an alternative to having students create their own videos, you may have students use videos that are readily available online (see "Colliding Pucks on an Air Table").

I provide students with individual feedback using written comments and assign additional practice exercises as needed in preparation for the summative assessment.

This assessment addresses all of the guiding questions for the unit.

Unit 5: Torque, Rotational Motion, and Angular Momentum

Laboratory Investigations:

- Weigh-Off Challenge
- Rolling Motion
- Conservation of Angular Momentum

Estimated Time:

4 weeks

Guiding Questions: ▼ What causes rotational motion? ▼ How is rotational motion described mathematically? ▼ What is the analog of mass in a rotational system?

Learning Objectives	Materials	Instructional Activities and Assessments
Use representations of the relationship between force and torque. [LO 3.F.1.1, SP 1.4] Compare the torques on an object caused by various forces. [LO 3.F.1.2, SP 1.4]	**Web** "Equilibrium Rule"	**Instructional Activity:** In this activity, multi-object balances (like mobiles) are used to introduce students to concepts of torque and rotational equilibrium and problem-solving strategies. Extensions include a study of Calder art.
Estimate the torque on an object caused by various forces in comparison to other situations. [LO 3.F.1.3, SP 2.3] 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] 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]	**Supplies** Materials that can be easily obtained from recycle bins (nothing purchased or ready-made can be used in the construction)	**Formative Assessment:** In the Weigh-Off Challenge Lab, students work individually to construct a torque-balance. Design parameters include mass range of 0.0–100.0 g, accuracy expectation within +/– 0.5 g, maximum construction not to exceed a mass of 0.750 kg, and the following maximum size limits: height = 20.0 cm, width = 15.0 cm, length = 25.0 cm. The construction must survive a 1.0 m fall onto its base. Students must include an Operation Manual with directions on use of their "product." Students construct their projects at home.
Use representations of the relationship between force and torque. [LO 3.F.1.1, SP 1.4] Compare the torques on an object caused by various forces. [LO 3.F.1.2, SP 1.4] Estimate the torque on an object caused by various forces in comparison to other situations. [LO 3.F.1.3, SP 2.3] 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]	Giancoli, Chapter 8: "Rotational Motion," Section 8-4 Hieggelke, Maloney, and Kanim	**Formative Assessment:** Students complete an assessment consisting of qualitative reasoning tasks, multiple-choice questions, and open-ended problem-solving questions designed to demonstrate understanding of principles of torque and rotational equilibrium.

In this video, Paul G. Hewitt, author of Conceptual Physics, *provides real-world examples to explain rotational equilibrium concepts. Students enjoy sharing their own experiences with torque and equilibrium — in particular, playground seesaws.*

I provide feedback directly to students in the form of corrections and comments on their papers to guide understanding and correct misconceptions. Depending on student performance, I may decide to reteach or reiterate some concepts in a different instructional manner.

Torque, Rotational Motion, and Angular Momentum

(continued)

Guiding Questions: ▼ What causes rotational motion? ▼ How is rotational motion described mathematically? ▼ What is the analog of mass in a rotational system?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	Okuma, Maloney, and Hieggelke	**Instructional Activity:** In this activity, the variables and dimensional units associated with rotational motion are introduced. In addition, moment of inertia is presented in conjunction with torque and rotational dynamics. This activity begins with comparisons of linear to rotational analogs with particular attention to dimensional analysis. I use a *Jeopardy!*-style group competition in which students solve Ranking Tasks to determine the level of student understanding and correct misconceptions.
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]	Giancoli, Chapter 8: "Rotational Motion," Sections 8-1 to 8-3, 8-5 to 8-7 **Supplies** Balls of various density (hollow and solid), inclined planes, metersticks, carbon target sheets	**Instructional Activity:** The Rolling Motion Lab investigation is similar to the Predicting Projectile Motion Range Lab and related formative assessment, found in Unit 1. In this guided-inquiry lab, students design an experimental plan to demonstrate and answer questions they generate about rotational motion. Also, students predict where on the floor a ball will land after the ball rolls down a ramp set on a table. They individually make predictions using energy principles and the equations of kinematics, applying these principles to rotational motion. During this activity, students can see others' results and adjust their predictions accordingly, either by correcting a mathematical misunderstanding or by trying to account for error associated with resistive forces.
		Formative Assessment: Working individually, students prepare a brief lab report of the Rolling Motion Lab. The report should include a description of the setup, the solution leading to the prediction along with a comparison to data, and explanation(s) to account for any discrepancies.

I find that student understanding of the topics in this unit is dependent on the level of mathematics the student has acquired. Some level of reiteration of mathematical relationships may be needed.

I provide feedback in written comments on students' reports, addressing any mathematical mistakes or misconceptions pertaining to their calculations and analysis.

Guiding Questions: ▼ What causes rotational motion? ▼ How is rotational motion described mathematically? ▼ What is the analog of mass in a rotational system?

Learning Objectives	Materials	Instructional Activities and Assessments
In an unfamiliar context or using representations beyond equations, 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] Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semiqualitatively. [LO 4.A.1.1, SP 1.2, SP 1.4, SP 2.3, SP 6.4] 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] 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] 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] 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] 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]	Giancoli, Chapter 8: "Rotational Motion," Section 8-8 **Video** "Figure Skating – Conservation of Angular Momentum" **Supplies** Low-friction rotating platform, weights (or heavy textbooks)	**Instructional Activity:** In this activity, which includes both structured- and guided-inquiry components, students are introduced to angular momentum and its conservation. First, students watch a video of a classic "scratch spin" in which an ice skater draws in her arms and legs, increasing spin rate tremendously. The students pose questions and discuss highlights of the video. They then discuss concepts of angular momentum and its conservation in relation to real-world applications. Next, using a rotating platform and weights, students design an experimental procedure for demonstrating the concepts they have discussed.

Torque, Rotational Motion, and Angular Momentum

(continued)

Guiding Questions: ▼ What causes rotational motion? ▼ How is rotational motion described mathematically? ▼ What is the analog of mass in a rotational system?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] 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] 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] 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] 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. [LO 5.E.2.1, SP 2.2]	**Supplies** Rotary motion sensors (Pasco), rotational accessories (Pasco), mass balances, calipers	**Instructional Activity:** In the Conservation of Angular Momentum Lab, groups of two to four students measure final angular speed of a system consisting of a non-rotating ring that is dropped on a rotating disk. Students compare the measured angular speed to the value predicted using the conservation of angular momentum.

I provide verbal feedback directly to students based on their lab results to guide and correct any conceptual and/or mathematical misunderstandings.

Guiding Questions: ▼ What causes rotational motion? ▼ How is rotational motion described mathematically? ▼ What is the analog of mass in a rotational system?

Learning Objectives	Materials	Instructional Activities and Assessments
All of the learning objectives in the unit are assessed.		**Summative Assessment:** Students take an exam consisting of various reasoning tasks, such as ranking and/or conflicting contentions problems, as well as multiple-choice and problem-solving questions. The exam is designed to assess students' mastery in the application and understanding of rotational motion and the law of conservation of momentum.

This assessment addresses all of the guiding questions for the unit.

Unit 6: Circular Motion and Gravitation

Laboratory Investigations:
- Circular Motion
- Conical Pendulum
- Kepler's Laws of Gravitation

Estimated Time:
4 weeks

Guiding Questions: ▼ How do you describe a change in motion? ▼ What keeps an object in motion? ▼ What is gravitational force?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	**Web** "Chapter 10. Uniform Circular Motion"	**Instructional Activity:** In this activity, I guide students through an introductory discussion on uniform circular motion. Students also create a list and description of "center-seeking" forces which can cause objects in motion to change their direction. I use vector demonstrations to illustrate how the acceleration is directed towards the center of the circular path. I also guide students through the derivation of the equation *centripetal* $a = v^2/r$ and a review of instantaneous radius of curvature.
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]	**Supplies** Pieces of string (1–1.5 m in length), washers or nuts to use as weights, tape, paper clips, pieces of PVC tubing (1/2 inch in diameter, 15–20 cm in length) or empty ballpoint pens, metersticks, timing devices, calculators	**Instructional Activity:** In the Circular Motion Lab, a guided-inquiry activity, groups of two to four students construct a circular motion apparatus and analyze the effect of tangential velocity on centripetal force. Students strategize within groups to determine how to measure orbital radius and keep speed uniform while maintaining a constant radius.
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]		**Formative Assessment:** Students complete individual lab reports for the previous lab investigation on circular motion. In the report, students must provide a procedural description of how radius was measured. The data analysis should include linearization (to find the ratio of hanging to whirling mass from best-fit slope) of radius versus velocity-squared.

I provide feedback in the form of written comments and corrections directly on individual lab reports.

Circular Motion and Gravitation

(continued)

Guiding Questions: ▼ How do you describe a change in motion? ▼ What keeps an object in motion? ▼ What is gravitational force?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	**Video** "Conical Pendulum" **Supplies** String, flying pig toys with flapping wings, protractors, metersticks, timers, calculators	**Instructional Activity:** In the Conical Pendulum Lab, a guided-inquiry activity, uniform circular motion with a conical pendulum is demonstrated using a flying pig toy. This activity is an extension of the previous lab activity with applications and reinforcement of vectors. During whole-class discussion, students discuss how to determine period of revolution and measure the circular radius and the angle that the tether makes with vertical. Students perform pre-lab calculations of a theoretical pig's speed and compare expected and measured speeds with an analysis of error sources.
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]	Giancoli, Chapter 5: "Circular Motion; Gravitation"	**Formative Assessment:** Students complete multiple-choice, conceptual, and open-ended problems related to centripetal acceleration and circular motion.
Approximate a numerical value of the gravitational field (*g*) 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] 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] 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 7.2]		**Instructional Activity:** In this activity, I introduce students to Newton's law of gravitation, satellites and weightlessness, and acceleration due to gravity *g* near the Earth's surface using a guided-discussion format interspersed with video clips of a reduced gravity environment (such as NASA's reduced gravity aircraft, or "Vomit Comet"). In the discussion, students explore the guiding questions for this unit. Since the law of conservation of angular momentum has already been introduced, elliptical satellite motion is also discussed.

Problems include kinematics and dynamics of circular motion as well as problems with unbanked and banked curves. I use student performance to determine the level of review needed for these topics and to design instructional activities to use when introducing circular motion in gravitation.

As my background is in geophysics, I especially like to discuss how variations in the surface measurements of Earth's gravity (due to Earth's inhomogeneities) are a very useful tool for geophysicists in finding oil and ore fields.

Circular Motion and Gravitation

(continued)

Guiding Questions: ▼ How do you describe a change in motion? ▼ What keeps an object in motion? ▼ What is gravitational force?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	**Web** "Gravity and Orbits"	**Instructional Activity:** In this activity, students build upon their foundational understanding of circular motion and are introduced to Kepler's three laws of planetary motion: the law of orbits, the law of equal areas, and the law of periods. I guide them through related derivations. Students individually use the PhET simulation to visualize and quantify the effects of varying orbital speed and radius on orbit stability.
Apply $g = G\frac{M}{r^2}$ to calculate the gravitational field due to an object with mass *M*, where the field is a vector directed toward the center of the object of mass *M*. [LO 2.B.2.1, SP 2.2] 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] Approximate a numerical value of the gravitational field (*g*) 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]	**Supplies** String, cardboard, push pins, graph paper, pencils, scissors, rulers, calculators **Web** "Kepler's Laws" "AP Physics C: Mechanics. 2005 Free-Response Questions," Question 2	**Instructional Activity:** In the Kepler's Laws of Gravitation Lab, a guided-inquiry activity, students individually design an investigation to verify Kepler's first two laws. Students also derive Kepler's third law and use it to predict orbital radius from orbital period and vice versa. They then apply what they have learned to complete a linearization problem from an AP Physics C Exam.
All of the learning objectives in the unit are assessed.		**Summative Assessment:** Students take an exam consisting of multiple-choice and free-response problems designed to assess mastery in the application and use of equations of centripetal acceleration and force and Newton's law of gravitation.

This assessment addresses all of the guiding questions for the unit.

Oscillations, Mechanical Waves, and Sound

Laboratory Investigations:

- Waves
- Speed of Sound
- Pendulum

Estimated Time:

4 weeks

Guiding Questions: ▼ How do waves/vibrations carry energy? ▼ What physical characteristics of a system govern its period of oscillation?

Learning Objectives	Materials	Instructional Activities and Assessments
Use graphical representation of a periodic mechanical wave to determine the amplitude of the wave. [LO 6.A.3.1, SP 1.4] 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] Use a visual representation of a periodic mechanical wave to determine wavelength of the wave. [LO 6.B.2.1, SP 1.4] 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] Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [LO 5.B.3.2, SP 2.2, SP 6.4, SP 7.2]	Giancoli, Chapter 11: "Vibrations and Waves," Sections 11-7 to 11-9 **Video** "Waves Introduction" **Supplies** Spring toys	**Instructional Activity:** In this activity, students are introduced to mechanical waves via a video, and they examine spring-toy models of modes of energy transport. During a teacher-facilitated discussion, I emphasize the following concepts: polarization, superposition of waves, and Huygens's principle. Students (in groups of two to three) use spring toys to generate compressional and shear energy modes and to demonstrate how input energy varies wave amplitude.
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] Describe representations of transverse and longitudinal waves. [LO 6.A.1.2, SP 1.2] Analyze data (or a visual representation) to identify patterns that indicate that a particular mechanical wave is polarized and construct an explanation of the fact that the wave must have a vibration perpendicular to the direction of energy propagation. [LO 6.A.1.3, SP 5.1, SP 6.2] 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]	**Supplies** Spring toys, metersticks, timers **Web** "Waves in a Slinky"	**Instructional Activity:** In the Waves Lab, a guided-inquiry activity, students work in groups of two to four to investigate the anatomy of waves and energy transport in longitudinal and transverse waves.

Guiding Questions: ▼ How do waves/vibrations carry energy? ▼ What physical characteristics of a system govern its period of oscillation?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] 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] 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] 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] 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]	Giancoli, Chapter 12: "Sound" **Web** "Sound"	**Instructional Activity:** In this activity, students individually use a simulation to investigate the Doppler effect, wave superposition, Huygens's principle, and beats. This simulation allows students to see sound waves and adjust frequency and volume.

Guiding Questions: ▼ How do waves/vibrations carry energy? ▼ What physical characteristics of a system govern its period of oscillation?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] 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] 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] 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] 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]	Giancoli, Chapter 12: "Sound" **Supplies** Large graduated cylinders, resonance tubes, metersticks, tuning forks	**Instructional Activity:** Students complete the Speed of Sound Lab after an introduction to standing wave nodes and antinodes. In this lab, which is a guided-inquiry activity, students in groups of two to four determine the speed of sound using the principle of resonance by finding the wavelength from a known frequency source. Students fill a graduated cylinder with water. The length of the air column can be varied by moving the resonance tube up and down in the water.
		Formative Assessment: Students complete an assessment consisting of multiple-choice and open-ended problems covering basic wave mechanics calculations and concepts.

I provide students feedback in the form of individual comments and corrections. I also pay particular attention to conceptual understanding of the material. Student performance helps guide any reteaching I may need to do to enable deeper understanding.

Guiding Questions: ▼ How do waves/vibrations carry energy? ▼ What physical characteristics of a system govern its period of oscillation?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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]	**Supplies** Hooke's Law apparatuses, springs of differing spring constants, weight hangers, slotted masses, rulers, timers	**Instructional Activity:** In this activity, Hooke's law and oscillations are explored via a teacher-directed demonstration of oscillations of masses on springs. Then, in groups of two to three, students informally investigate relationships between mass and period for springs of differing spring constants.
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] 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] 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]	Giancoli, Chapter 11: "Vibrations and Waves" **Supplies** String, plumb bobs (or suitably equivalent masses), protractors, metersticks, timers	**Instructional Activity:** In the Pendulum Lab, a guided-inquiry activity, groups of two to four students determine the acceleration due to gravity using a simple pendulum. Students design experimental plans to investigate mass- and angle-dependence. Extensions can include linearization of the L versus T^2 graph to connect slope to value of gravity.
All of the learning objectives in the unit are assessed.		**Summative Assessment:** Students take a comprehensive exam on wave mechanics and simple harmonic motion.

I provide students feedback in the form of individual comments on their lab reports. My comments focus on any misunderstanding of error analysis, graphing and linearization methods, and/or mass-dependence analysis.

This assessment addresses all of the guiding questions for the unit.

Unit 8:

Introduction to Electric Circuits

Laboratory Investigations:

- Ohm's Law
- Series and Parallel Circuits
- Electrical Energy and Power

Estimated Time:
4 weeks

Guiding Questions: ▼ What makes charge move? ▼ How is electric energy stored? ▼ How does a power company determine energy costs?

Learning Objectives	Materials	Instructional Activities and Assessments
Make claims about natural phenomena based on conservation of electric charge. [LO 1.B.1.1, SP 6.4] 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] 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] 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] Use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges. [LO 3.C.2.1, SP 2.2, SP 6.4] 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]	**Web** "Charges and Fields"	**Instructional Activity:** In this activity, students observe a teacher-directed demonstration on electrostatic induction and are introduced to charge. Students then work with an online simulation to determine the variables that affect how charged bodies interact. They also predict how charged bodies will interact and describe the strength and direction of the electric field around a charged body. Next, in teacher-facilitated discussions and through the use of illustrations and diagrams, students develop an understanding of how free-body diagrams and vector addition help explain and quantify the interactions.
	Giancoli, Chapter 16: "Electric Charge and Electric Field"	**Formative Assessment:** Students work through problem-solving questions similar to those from Giancoli, Sections 16-1 to 16-6. This activity assesses student understanding of electrostatics and problem-solving skills.

This activity emphasizes the parallels between Coulomb's law and Newton's law of gravitation. I usually discuss the pitfalls of sign allocation due to the historical definition of current direction versus actual electron flow.

At the conclusion of this activity, students should be able to draw and articulate parallels to mechanical systems — in particular, gravity acting on fluid flow within a pipe.

I provide feedback directly to students using written comments and individual conferences to address any misunderstandings regarding charge of electrons; current flow magnitude and direction; FBDs; and problem solving involving Coulomb's Law with use of vector components, magnitudes, and signs.

Introduction to Electric Circuits

(continued)

Guiding Questions: ▼ What makes charge move? ▼ How is electric energy stored? ▼ How does a power company determine energy costs?

Choose and justify the selection of data needed to determine resistivity for a given material. [LO 1.E.2.1, SP 4.1]	**Web** "Ohm's Law"	**Instructional Activity:** This activity uses an online simulation to introduce students to voltage, resistance, and resistors. Students vary input values and note the effects of changing resistance and/or voltage on electric current.
	Supplies Batteries of various voltages, resistors of varying resistances, breadboards, current sensors, digital multimeters (ohmmeters)	**Instructional Activity:** In the Ohm's Law Lab, groups of two to four students experimentally verify Ohm's Law and confirm their findings by predicting resistance of known resistor elements. Students also measure current flow for various applied voltages across varying resistors.
		Formative Assessment: Students individually complete a lab report about the previous activity. The report should include calculations of current, voltage, and resistance combinations from the lab and additional ranking tasks provided at the end of the lab.

I find it essential to revisit the importance of dimensional analysis as there are a plethora of derived units associated with E&M.

Students will need to be instructed on the use of multimeters.

After reading students' reports, I conference with lab groups to address misconceptions. This helps to ensure that students are ready to progress to studying more complex circuits.

Introduction to Electric Circuits

(continued)

Guiding Questions: ▼ What makes charge move? ▼ How is electric energy stored? ▼ How does a power company determine energy costs?

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] Apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule ($\sum \Delta V = 0$) 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] 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] 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] 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] 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.2.2, SP 1.4, SP 2.2]	**Web** "Multi-Loop Circuits and Kirchoff's Rules"	**Instructional Activity:** Students conduct research using Web sites such as the one listed here to visually define junctions and branches in multi-loop circuits and to learn to apply Kirchoff's rules. Students share their findings, questioning one another and defending their responses. I then provide and discuss additional examples of Kirchoff's loop and junction rules.
	Supplies Light bulbs, batteries, wires, alligator clips	**Instructional Activity:** In the Series and Parallel Circuits Lab, groups of two to four students design and implement a plan to investigate how batteries push electrons through simple circuits with light bulbs connected in series and in parallel.
		Formative Assessment: Students individually complete lab reports on the previous activity and solve problems testing their understanding of the mathematical relationships in circuits.
	Giancoli, Chapter 18: "Electric Currents," Sections 18-1 to 18-4	**Formative Assessment:** Students complete an assessment that includes diagrams of differing circuit arrangements. Students predict current flow direction and magnitude going through each branch of the circuit.

I provide feedback to students on their lab calculations and remediate any misunderstandings or misconceptions by conferencing individually with students prior to the next formative assessment.

If students do not perform well on this exam, I provide additional instruction and remediation exercises to reteach and reinforce calculations from lab activities.

Guiding Questions: ▼ What makes charge move? ▼ How is electric energy stored? ▼ How does a power company determine energy costs?

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] Apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule ($\sum \Delta V = 0$) 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] 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] 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] 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] 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.2.2, SP 1.4, SP 2.2]	**Web** "Energy Audit Activity, Teacher's Guide"	**Instructional Activity:** In this activity, students investigate energy consumption in their home and devise a plan for calculating and decreasing energy use. Students also make a home appliance inventory and use their electric bill to make energy cost calculations. Extension projects can include an analysis of school energy use and a proposal to school administrators about improving energy efficiency and the related cost savings.
	Supplies Current and voltage probe systems, interface and software for data collection, ring stands, wooden dowels, wires, alligator clips, electric motors, mass sets, strings, utility clamps	**Instructional Activity:** In the Electrical Energy and Power Lab, a guided-inquiry activity, groups of two to four students measure the power and electrical energy used by an electric motor used in a rudimentary elevator. Students also explore the gain in potential energy of a mass lifted by the motor.

Good pre-lab demonstrations include showing how the efficiency of a motor varies at different speeds and how a hand-cranked generator can function as a motor and vice versa.

Guiding Questions: ▼ What makes charge move? ▼ How is electric energy stored? ▼ How does a power company determine energy costs?

All of the learning objectives in the unit are assessed.		**Summative Assessment:** Students take an exam consisting of ranking tasks, multiple-choice questions, and free-response problem-solving questions similar to those in prior formative assessments in the unit. The exam also includes power-related questions and problems to assess mastery in the application and use of fundamental equations of electric circuitry.

This assessment addresses all of the guiding questions for the unit.

Resources

General Resources

Giancoli, Douglas C. *Physics: Principles with Applications.* 7th ed. New Jersey: Addison-Wesley, 2013.

Hewitt, Paul G. *Conceptual Physics*. 11th ed. Boston: Addison-Wesley, 2011.

Hieggelke, Curtis J., David P. Maloney, and Stephen E. Kanim. *Newtonian Tasks Inspired by Physics Education Research: nTIPERs*. Boston: Addison-Wesley, 2012.

O'Kuma, Thomas L., David P. Maloney, and Curtis J. Hieggelke. *Ranking Task Exercises in Physics*. Boston: Addison-Wesley, 2004.

Unit 1 (Kinematics) Resources

"4: The Motion of Projectiles." Walter Lewin. MIT OpenCourseWare. Accessed May 2, 2014. http://ocw.mit.edu/courses/physics/8-01-physics-i-classical-mechanics-fall-1999/video-lectures/lecture-4/.

"Describing Motion with Diagrams." Physics Classroom. Accessed May 2, 2014. http://www.physicsclassroom.com/Class/1DKin/U1L2b.cfm.

Frames of Reference. Physical Science Study Committee. Produced by Richard Leacock. 1960. Video, 26:00. Internet Archive. Accessed May 2, 2014. https://archive.org/details/frames_of_reference.

Fullerton, Dan. *AP Physics 1 Essentials: An APlusPhysics Guide*. Webster, NY: Silly Beagle Productions, 2013.

"Interpreting Distance–Time Graphs." MARS Shell Center, University of Nottingham and UC Berkeley. Accessed April 17, 2014. http://opi.mt.gov/pdf/CCSSO/InterpTimeDistance.pdf.

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.

"Kinematics Graph Activity." Jerry Stanbrough. Physics at BHS. Accessed May 2, 2014. http://www.batesville.k12.in.us/physics/phynet/mechanics/kinematics/Labs/graph_wksht_1.htm.

"The Moving Man." PhET. University of Colorado at Boulder. Accessed May 2, 2014. http://phet.colorado.edu/en/simulation/moving-man.

"Projectile Motion." PhET. University of Colorado at Boulder. Accessed May 2, 2014. http://phet.colorado.edu/en/simulation/projectile-motion.

"Ticker Tape Demo_2." Antonia Warren. YouTube. Video, 3:37. Accessed May 2, 2014. http://www.youtube.com/watch?v=8dhsuOn90PM.

Unit 2 (Newton's Laws of Motion) Resources

"2D Motion." Patrick Foley. PhET. University of Colorado at Boulder. http://phet.colorado.edu/en/contributions/view/3595.

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