AP® Physics 1: Algebra-Based

Course Planning and Pacing Guide

Kelly H. Burke
Woodstock High School
Woodstock, Georgia

About the College Board

The College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900, the College Board was created to expand access to higher education. Today, the membership association is made up of over 6,000 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, the College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success — including the SAT® and the Advanced Placement Program®. The organization also serves the education community through research and advocacy on behalf of students, educators and schools. For further information, visit www.collegeboard.org.

AP Equity and Access Policy

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

Woodstock High School
Woodstock, Georgia

School	Woodstock High School is a traditional four-year public high school located in Cherokee County, Georgia — a suburban county of Atlanta.
Student population	The student population is socioeconomically diverse. Students come from families with highly educated parents and above-average incomes, as well as from families where the parents are unskilled workers or unemployed and income is low. Approximately 33 percent of the student population participates in the free or reduced-price lunch programs. Approximately 72 percent of the student population is white, 25 percent Hispanic and African American, and the remainder is composed of East Asian, South Asian, and multiracial ethnicities. Approximately 80 percent of students are on a college-preparatory diploma program and 17 percent are on a career/technical graduation plan.
Instructional time	Woodstock High School follows a modified school calendar: the summer break is shortened to eight weeks and there are week-long breaks during the months of September and February, in addition to the traditional breaks for holidays and spring break. The school year begins the first week of August and concludes during the last week of May. Students attend 180 days of class. The school day is structured around seven 57-minute periods, five days per week; there are no extended class periods.
Student preparation	For the majority of students, AP Physics 1 is offered during the junior year of high school after successful completion of Honors Chemistry. The AP Physics 2 course is offered to students who have completed either AP Physics 1 or a general introductory physics course.
Primary planning resources	Appel, Kenneth, Clarence Bakken, John Gastineau, and David Vernier. *Physics with Vernier*. Beaverton, OR: Vernier Software & Technology, 2010. Knight, Randall D., Brian Jones, and Stuart Field. *College Physics: A Strategic Approach*. 2nd ed. Boston: Addison-Wesley Publishing, 2009. Knight, Randall D., Brian Jones, Stuart Field, and James H. Andrews. *Student Workbook for College Physics: A Strategic Approach*. 2nd ed. Boston: Addison-Wesley Publishing, 2009. O'Kuma, Thomas L., David P. Maloney, and Curtis J. Hieggelke. *Ranking Task Exercises in Physics*. Boston: Addison-Wesley Publishing, 2004.

Overview of the Course

The premise of the revised AP Physics 1 course is to more closely mirror the expectations, rigor, and content of an introductory college-level physics course by exposing students to a broader range of instructional activities. Students benefit from a reduction in the number of learning objectives, as it provides more time to develop and refine deeper understandings of the principles and strategies of inquiry and critical thinking that are a part of any post-secondary physics course. The AP Physics 1 course is built upon fundamental concepts called *enduring understandings* and their application by way of the science practices. These concepts are the foundation of the curriculum and support the overarching themes of AP Physics 1, called the *big ideas.*

The role of the teacher as a lecturer responsible for complete content presentation has shifted toward that of facilitator, with the challenging task of guiding students to discover, develop, and refine the enduring understandings of higher-level physics by participating in activities that promote inquiry, critical thinking, experimental design, and data analysis. With this pedagogical shift comes a greater emphasis on learning by doing and a diminished focus on lectures and mathematical routines. The course requires that students spend 25 percent of instructional time engaged in laboratory activities where the seven science practices are emphasized. Students keep a laboratory notebook in which they record their observations, data, and final lab reports.

There will be instances where the basic concepts necessary for an inquiry-based activity are addressed outside of the classroom — allowing students to utilize all available resources, including the collaborative efforts and creative input of their peers. One interesting aspect of this revised approach is the opportunity and means to extend the learning process. The possibility of extending an activity feeds the innate curiosity of young adults, and it fosters the inevitable crossover into other science and math disciplines and exposure to careers in the sciences.

In my classroom, students are arranged into small groups around lab tables; this facilitates collaboration on most tasks. The lab tables permit displays and manipulatives to be placed within students' reach. One of my favorite instructional activities that utilizes these table groups is Ranking Tasks (O'Kuma 2004). Initially, students work independently, then as table groups, and finally with the whole class as they evaluate and rank situations involving applications of physics principles.

Assessment of the learning objectives takes place in a variety of formats. There is the traditional unit assessment modeling the AP Physics 1 test, with sections devoted to conceptual understanding, student experimental design, and applications of inquiry-based learning. Performance assessments in which laboratory skills, techniques, and data and error analysis are evaluated are also utilized. As with any course, the use of formative assessments is a critical component. Formative assessments are the compass points that indicate readiness to advance within the learning progression. Formative assessments may be as direct as a student's written or oral response to a teacher's question or as subtle as students showing thumbs up or down to indicate their confidence in a conclusion or outcome. I also have a classroom set of student-response devices (clickers), which allow me to observe responses from students throughout a class period. The clickers are set for "spontaneous survey"; this allows me to ask a question (either multiple choice or numeric) and display students' anonymous responses. This lets me quickly see how many students understand an idea or calculation. That instant assessment guides the flow of most of my classes.

In general, there is a relaxed atmosphere in my classroom, which encourages peer collaboration on many activities. Since students are accustomed to speaking with their table group, I can walk around the classroom and hear their discussions, and this provides me with information about their mastery of a particular topic.

Unit 1: Kinematics in One Dimension

Laboratory Investigations:

- Graph Matching
- Graphical Analysis of Motion
- Cart on a Ramp
- Indirect Measurement of Height Using Kinematics
- Determining *g* on an Incline

Estimated Time:

3 weeks

Guiding Questions: ▼ How are multiple representations (i.e., words, graphs, and equations) used to describe an object's motion? ▼ How do scalar measurements differ from vector measurements? ▼ How are kinematics equations and graphs used to describe objects in free fall?

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] 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]	Knight, Jones, and Field, Chapter 2: "Motion in One Dimension"	**Instructional Activity:** I introduce the unit with a variety of objects in motion: a marble rolling across a slick tabletop, a box sliding to a stop on same table top, an object dropped from ceiling height, a lab cart rolling down an inclined plane, an inverted lab cart sliding slowly down the same incline, a ball tossed with an arc, a ball tossed straight up, and a toy dart gun that fires a dart horizontally and then downward. In small groups, students work together to group the actions according to similar types of motion. Each group then shares and defends their findings.
	Appel et al., "Graph Matching" Laptops, Vernier Motion Detectors	**Instructional Activity:** This activity requires students to walk toward and away from the motion detector in order to re-create the displayed graph. Both position-time and velocity-time graphs are available. Students begin with a position-time graph, discussing what motion is depicted, and then plan a way to re-create the graphed motion. Feedback is instantaneous in that the graphs of the students' motion are superimposed on the provided graph. Students may repeat as often as necessary. To differentiate instruction, groups that achieve the goal quickly may advance to one of the velocity-time graphs, while struggling groups continue with a different position-time graph. I provide feedback directly to students during the activity. Final graphs are printed and displayed as references for future discussions.
	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Position Time Graphs—Displacement"	**Instructional Activity:** Students work in small groups to properly rank five position-time graphs in order of displacement from least to greatest. A significant aspect of this task is for the students to state, either verbally or in writing, the reasoning behind their ranking; following this, students rate their confidence in their ranking.

This activity leads students to thinking about and describing the ways in which an object may move (vertically, horizontally, constant speed, speeding up or down, one dimension or two, etc.).

Accelerated motion is first introduced with velocity-time graphs, followed by acceleration graphs. Once these graphs are mastered, the students are then introduced to the kinematics equations for uniformly accelerated motion: "The Big 3." My belief is that students are able to continue with the graphs more efficiently by adding one more idea of acceleration than they are being presented with three initially scary equations and returning to graphs later.

Ranking tasks ask students to go beyond memorize-and-recall strategies and instead apply the concepts that are being learned. Typically, calculators are not used; this forces students to think about concepts rather than "pick an equation." Being asked to rank six items requires a greater understanding and application than selecting a single greatest or least item.

Guiding Questions: ▼ How are multiple representations (i.e., words, graphs, and equations) used to describe an object's motion? ▼ How do scalar measurements differ from vector measurements? ▼ How are kinematics equations and graphs used to describe objects in free fall?

Learning Objectives	Materials	Instructional Activities and Assessments
Make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. [LO 4.A.2.1, SP 6.4] 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** "1.3 Predicting Motion from Graphs"	**Instructional Activity:** In this student-centered simulation activity, several different position-versus-time graphs are provided. From the provided graphs, students individually construct motion, velocity-versus-time, and acceleration-versus-time graphs. For each position-time graph, a follow-up simulation plots in real time the correct velocity and acceleration graphs, allowing students to evaluate the graphs constructed from their predictions.
	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Position Time Graphs—Average Speed"	**Instructional Activity:** Working in small groups, students rank the average speed, greatest to least, for six position-time graphs. Along with interpreting a position-time graph and analyzing slope, the students must demonstrate understanding of speed versus velocity in this activity.
Design an experimental investigation of the motion of an object. [LO 3.A.1.2, SP 4.2]	Variety of sports balls, Vernier Motion Detectors, laptops	**Formative Assessment:** Using any sports ball and the motion detector, students working in small groups design a lab using the motion of a rolling ball. Each group produces a position-time graph and a velocity-time graph for the ball's motion. The graphs are then printed. Assessment occurs when the groups exchange graphs, and one group must express to the creators of a particular pair of graphs the motion that is represented graphically. Groups may continue to swap graphs until each group interprets one set correctly. With most graphical-analysis situations, I train my students to write on the lines of the graph and to describe the significance of the slope or area under, or positive/negative value, so that the informational notes are present alongside the actual graph curve.

Each ActivPhysics simulation is accompanied by objectives and a summary. They can be used in a variety of applications. I often assign the simulations as homework. The simulations lead students through a learning progression reinforcing a particular concept. When completed at home, students make a two-column chart. The left column is titled "What I Did," indicating the variable that was manipulated. The other column: "What I Observed and Why it Happened That Way."

I provide verbal feedback to students during the activity, and I may also work individually with a select group to reteach misunderstood concepts.

Kinematics in One Dimension

(continued)

Guiding Questions: ▼ How are multiple representations (i.e., words, graphs, and equations) used to describe an object's motion? ▼ How do scalar measurements differ from vector measurements? ▼ How are kinematics equations and graphs used to describe objects in free fall?

Learning Objectives	Materials	Instructional Activities and Assessments
Make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. [LO 4.A.2.1, SP 6.4] 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** "Accelerated Motion: A Data Analysis Approach"	**Instructional Activity:** This online activity walks students through the process of producing an acceleration-time graph when starting with position and time. A motion graph leads to a position-time graph, and then slopes of tangent lines lead to a velocity-time graph and velocity calculations. From the velocity-time graph, an acceleration-time graph is produced, and the significance of the area below the curve is developed. If completed in class, I check each group for understanding. A whole-class discussion follows, wherein I specifically target certain aspects of the activity, such as area under the graph. To conclude, I display a position-time graph and ask each student to create an appropriate acceleration-time graph. This is a "Ticket Out the Door" activity: students must show the correct graph before the class period ends.
	Web "Accelerated Motion: Practice with Data Analysis"	**Formative Assessment:** Students are presented with three data tables containing values for position and time. Students determine the value for the acceleration of the object. They work in pairs or table groups of four. Groups compare results as I circulate among them assessing understanding and progress, and providing feedback.
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]	Appel et al., "Cart on a Ramp"	**Instructional Activity:** In this inquiry-based activity, students observe the motion of a cart that has been given an initial velocity up an inclined plane. As the cart rises up the plane, it slows, stops, and then accelerates back down the incline, eventually rolling onto a horizontal surface. The motion detector and software produce real-time graphs of the position, velocity, and acceleration. Students also predict the resulting changes in the graphs as the angle of incline is increased. This activity extends to the idea of a coin being tossed upward and how its motion compares to that of the cart on the incline.

The lessons and activities available at the PhysicsLAB site are numerous. A teacher can find introductory instructional-resource lessons and print worksheets to be used for additional practice, quizzes, review, and remediation. In this course planning guide, I will not list each and every activity from PhysicsLAB that I might use because it differs depending on the progress of my students. However, I will highlight a few favorites that I reuse each year.

I work individually with struggling groups, or I pair a struggling group with an accomplished group for peer instruction.

This lab serves as a wonderful summative activity. Students can begin by verbalizing the kinds of motion that are exhibited by the cart as it rolls up, pauses, rolls back down, and then possibly rolls onto a horizontal surface. Next, all three kinematics graphs can be sketched as predictions, followed by the use of the motion detector to produce real-time graphs. Students can self-assess by comparing their predicted graphs with the computer-generated ones.

Kinematics in One Dimension

(continued)

Guiding Questions: ▼ How are multiple representations (i.e., words, graphs, and equations) used to describe an object's motion? ▼ How do scalar measurements differ from vector measurements? ▼ How are kinematics equations and graphs used to describe objects in free fall?

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]	**Online video** "The Apollo 15 Hammer–Feather Drop"	**Instructional Activity:** This video clip shows astronaut Dave Scott dropping a hammer and a feather while on the moon, demonstrating the uniform acceleration of gravity on freely falling objects in the absence of air resistance. Table groups have 3 minutes to list three physics-related observations after watching the video; groups then share their observations. Afterward, I continue the class discussion, leading students toward working definitions of *free fall*, *gravity*, and *air resistance*.
	Tennis ball	**Instructional Activity:** As class begins, I perform several demonstrations with a ball and ask students to respond yes or no to whether the ball is in free fall. I begin by dropping a ball from rest, then I toss it upward, throw it downward, throw it in an arc to a student, bounce the ball, launch it with a slingshot, etc.
	Teacher-produced problem set: kinematics equations – horizontal	**Instructional Activity:** This is a set of word problems created using the QUEST program. I have the option of printing the problem set to be copied as a handout or assign it to be completed online. This set of problems addresses events taking place along a horizontal surface. I can also create a similar set of problems to be placed on my website for additional practice, as QUEST assignments are in PDF format.

Typically, students all agree that the dropped ball is in free fall, but that is where the agreement ends. I point out that all of the actions are examples of free fall, and then I make a point of identifying misconceptions in order to correct them.

Typically, problem sets are assigned as homework. I usually work through one at the end of class to model the correct steps for a complete solution. My solutions are always available for students to view before school the next day. This allows those unsure about their work to check their answers and to seek additional help from me or a classmate if needed, prior to the beginning of class.

Guiding Questions: ▼ How are multiple representations (i.e., words, graphs, and equations) used to describe an object's motion? ▼ How do scalar measurements differ from vector measurements? ▼ How are kinematics equations and graphs used to describe objects in free fall?

Learning Objectives	Materials	Instructional Activities and Assessments
Make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. [LO 4.A.2.1, SP 6.4] 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** "Linear Kinematics Quiz 1"	**Formative Assessment:** This online quiz is not submitted for a grade but allows students to gauge their own mastery of the kinematics equations. This takes place a day or two after the kinematics equations are introduced, following a homework assignment. After answering seven calculations-based problems, students receive immediate feedback. Eighty-five percent correct is the class goal. Students may try additional sets of similar problems until they are comfortable with the application of the equations or have reached their goal score.
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]	Teacher-produced problem set: free fall	**Instructional Activity:** This is a second set of word problems, focusing on those involving free fall. Students must pay closer attention to the signs of displacement, velocities, and acceleration with free-fall problems than with horizontal-motion problems.
Design an experimental investigation of the motion of an object. [LO 3.A.1.2, SP 4.2]	Stopwatches, long tape measure, protractors, smartphone Vernier Video Physics app, PASCO Freefall System, several balls of various sizes, densities, and color	**Formative Assessment:** Students are placed into four lab groups and taken to the gym. Each group devises a method to determine the height from the gym floor to the track above. Some possibilities are to use a stopwatch to time a dropped ball, indirectly measure height using a protractor, use the PASCO Freefall System, or use the Vernier Video Physics app and make a video to aid in their calculations. The first group to finish measures the actual height with a tape measure. In 2012–2013, our district allowed students to use their own learning devices during class with teachers' permission. By 2014–2015, physics apps and other programs will be plentiful and a natural part of the learning process.

Physics 24/7 is a great site for self-quizzes and additional practice. The self-quizzes are my favorite. I can project these onto the whiteboard during class for review and choose a student's answer to enter for immediate feedback; or students may self-assess at home. Students could also respond with their clickers.

I provide feedback as groups compare their indirect height measurements to the height measured directly with the tape measure. Unsuccessful groups may perform their trial again after receiving some guidance from me.

Guiding Questions: ▼ How are multiple representations (i.e., words, graphs, and equations) used to describe an object's motion? ▼ How do scalar measurements differ from vector measurements? ▼ How are kinematics equations and graphs used to describe objects in free fall?

Learning Objectives	Materials	Instructional Activities and Assessments
Analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [LO 3.A.3.1, SP 6.4, SP 7.2]	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Rocks Thrown Downward—Acceleration"	**Instructional Activity:** This ranking task presents six situations in which rocks of various masses are falling downward with various initial velocities. The students rank them according to their accelerations. This 5-minute activity quickly reinforces and assesses the idea of acceleration due to gravity as a constant value. Students present their rankings to the whole class and time is allowed for point-counterpoint type discussion. After that, I prompt students with possible variations, such as the presence of air resistance, a strong crosswind, hollow rocks, trying this on the moon, etc.
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]	**Web** "1.7 Balloonist Drops Lemonade"	**Instructional Activity:** In this online activity, students begin with the idea of a cup of lemonade being dropped from an ascending hot air balloon. The simulation shows the slow motion initial ascent of the dropped lemonade followed by its descent. The graphs of the lemonade's motion are combined with the kinematics equations for a complete description of the motion. This is followed by a word problem on the whiteboard, reinforcing the concept just explored.
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]	Appel et al., "Determining *g* on an Incline" PASCO Dynamics Carts and Dynamics Tracks, timers, angle indicators, Vernier Motion Detectors, laptops	**Instructional Activity:** Working in small groups, students use the motion detector to measure the speed and acceleration of a cart rolling down an incline. The mathematical relationship between the angle of incline and the acceleration of the cart is also investigated. In addition, by extrapolating the acceleration versus sine of the incline angle, students may determine the acceleration during free fall. The groups share their results and must state the significance of the acceleration of the cart when the angle is 90°. Groups must also reason and explain why the accelerations between zero and 90° are less than the free-fall acceleration. Peer critique of claims is provided through whole-group discussion.

Many students initially believe that an object thrown downward has a greater acceleration than one dropped from rest. This activity reveals that common misconception and creates an opportunity for the teacher to correct it and to continue to mention the relationship between force and acceleration as a precursor to later topics.

Students have a difficult time with the idea of a dropped object having an initial upward velocity. They assume dropped always means "from rest." Demonstrating this in the classroom is difficult, since some sort of slow-motion video is necessary; this online simulation is a nice alternative.

Arriving at the idea that the acceleration varies with angle of incline is pretty simple. The critical-thinking aspect of this exercise appears in the "why?" follow-up. Students have not been exposed to the concept of gravitational force yet, so it is interesting to see who is able to deduce the way in which the components of the gravitational force behave and influence the acceleration on an incline.

Guiding Questions: ▼ How are multiple representations (i.e., words, graphs, and equations) used to describe an object's motion? ▼ How do scalar measurements differ from vector measurements? ▼ How are kinematics equations and graphs used to describe objects in free fall?

Learning Objectives	Materials	Instructional Activities and Assessments
All of the unit's learning objectives are assessed.	Teacher-produced unit assessment	**Summative Assessment:** A unit assessment is given, following the College Board format of a multiple-choice section and a section of free-response questions. In both sections of the test, the three pedagogical approaches to kinematics are assessed: graphical analysis, narrative explanations, and algebra-based word problems. Special attention is given to situations involving motion along a horizontal surface as well as objects in free fall. One short answer is devoted to assessing one of the lab activities.

All of the guiding questions in this unit are addressed in this assessment.

Unit 2:

Kinematics in Two Dimensions

Laboratory Investigations:

- Displacement Vectors
- Horizontally Launched Projectiles
- Projectiles Launched at an Angle

Estimated Time:

3 weeks

Guiding Questions: ▼ Why is knowledge of vectors and component calculation vital to understanding two-dimensional motion? ▼ How are the kinematics equations applied to objects experiencing motion in two dimensions? ▼ How do variables such as launch angle, velocity, and altitude affect the maximum height and range of a launched projectile? ▼ What do we mean when we say that the horizontal motion of a projectile is independent of its vertical motion?

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]	Knight, Jones, and Field, Chapter 3: "Vectors and Motion in Two Dimensions" Vector cards, rulers, protractors, calculators	**Instructional Activity:** I make laminated cards with vectors drawn on them. Each card is marked with a letter. Students use rulers and protractors to measure magnitude and direction of the vectors. Students swap cards until at least two vectors from each quadrant have been measured. Students then calculate the *x* and *y* components for each vector.
	Web "Components Quiz 1"	**Formative Assessment:** This online quiz presents the vector with a written description and requires students to calculate a particular component. After solving the questions, the students can self-check their answers to gain a better sense of their understanding of the concepts. A score of 85 percent or better is the goal. Students scoring below that may link to an online lesson on vector components before trying another set.
	Vector cards	**Instructional Activity:** After a brief lesson on adding vectors, students can use the vector cards to add groups of three or four vectors. Either graphical addition or algebraic addition using the *sum of the components* can be used.
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]	Laminated treasure maps, Vis-à-Vis pens	**Formative Assessment:** I provide each group of students with a "Pirate Treasure Map." On an 8½" × 17" sheet of gridded paper, I draw five to seven scale vectors connected head to tail. These treasure maps are laminated so that students are able to mark on them with Vis-à-Vis pens. Students measure magnitude and direction of each, calculate *x* and *y* components, and add the vectors to determine the magnitude and direction of the resultant vector. Since the displacement vectors are drawn head to tail, most of them do not originate on an *x* axis. This causes problems for some students in measuring the angle with a protractor. Students may need help in using the protractor correctly and expressing the angles as measured from the positive *x* axis.

Prior to a unit on two-dimensional motion, I include a thorough study of vectors. The upcoming activities accomplish this goal. These learning objectives apply to force vectors, which will come later; I choose to treat vectors with displacement and velocity at this point in the curriculum.

When completed in class, I view the score reports and aid students having difficulty before the student attempts a second set. When completed at home, students are able to email scores to me. Depending on the students' demonstrated depth of knowledge, I may take additional time in class to reteach vector components.

To check results, students compare their calculated magnitude and direction with the measured magnitude and direction, and they calculate percent difference of the two. I also provide direct feedback to students; if the results are outside the desired range, I assist the group and guide them in locating their error, which usually involves an incorrect angle measurement.

Kinematics in Two Dimensions

(continued)

Guiding Questions: ▼ Why is knowledge of vectors and component calculation vital to understanding two-dimensional motion? ▼ How are the kinematics equations applied to objects experiencing motion in two dimensions? ▼ How do variables such as launch angle, velocity, and altitude affect the maximum height and range of a launched projectile? ▼ What do we mean when we say that the horizontal motion of a projectile is independent of its vertical motion?

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]	Smartphones with compass, 10 m lengths of string marked in 1 m intervals, meterstick	**Instructional Activity:** This is a smartphone lab that uses the compass feature; it takes place outside on a nice day. Groups of students begin at a common point and they must negotiate at least five displacement vectors to reach a common destination point. Ten-meter lengths of string, marked in one-meter increments, are used to measure distance, and the smartphone compasses provide the angles. The goal is to calculate the magnitude and direction of the resultant displacement from starting point to destination. Students post their results of magnitude and displacement in class.
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]	Projectile launcher, metersticks	**Instructional Activity:** After a teacher-led discourse on two-dimensional motion and an introduction to projectiles launched horizontally, the class observes several horizontal launches, with students operating the launcher and marking and measuring the landing positions. At the board, I guide a whole-group discussion, leading students through the calculations to eventually arrive at the initial launch velocity.
	Projectile launcher, metersticks, target	**Instructional Activity:** Each lab group is assigned a different launch height. The groups independently calculate the horizontal displacement for the projectile launched from their assigned heights. Students place the target at the calculated location and launch. On the target, I have written scores, as on a dartboard. The students earn a score depending on where the projectile lands. Groups who are terribly off can redo the activity; to earn a do-over, a group receives a new launch height and must show me their revised calculations.

Once back in the classroom, all of the results are viewed and compared. Allow for quite a bit of variance due to the somewhat primitive string ruler. The results should agree enough to sufficiently demonstrate that regardless of the path taken the displacement is the same.

This is the first use of the PASCO marble launcher. Take time to show students how to operate the launcher safely. The launcher provides opportunities for instructional enrichment and differentiation by varying the launch force or altitude, having a hoop placed at maximum height, or placing the target on an elevated perch, etc.

The target is a piece of cardboard covered by a smooth piece of aluminum foil. When the projectile strikes the target, it leaves a divot, which removes any doubt as to landing position. A Sharpie is used to color the divot to avoid duplication.

Kinematics in Two Dimensions

(continued)

Guiding Questions: ▼ Why is knowledge of vectors and component calculation vital to understanding two-dimensional motion? ▼ How are the kinematics equations applied to objects experiencing motion in two dimensions? ▼ How do variables such as launch angle, velocity, and altitude affect the maximum height and range of a launched projectile? ▼ What do we mean when we say that the horizontal motion of a projectile is independent of its vertical motion?

Learning Objectives	Materials	Instructional Activities and Assessments
Analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [LO 3.A.3.1, SP 6.4, SP 7.2]	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Water Over a Waterfall—Time to Reach Ground"	**Formative Assessment:** Waterfalls of different heights are shown with varying water velocities. Students rank the waterfalls based on the length of time for the water to reach the ground. Students work individually for 5 minutes and then in table groups for 3 minutes, arriving at a group decision before their answers are discussed. Next, each group presents their findings and a point-counterpoint discussion takes place until correct ranking has been accomplished.
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]	Teacher-produced problem set: horizontally launched projectiles Horizontal projectiles, student clickers	**Instructional Activity:** Using the QUEST question bank, I create sets of word problems focused on horizontally launched projectiles. If begun in class, I may have students use their clickers to enter the answer to the first problem; this way I can assess whether the students are ready to continue on their own at home later.
	Web "Projectile Motion Quiz 2"	**Formative Assessment:** Time permitting, this may be done on classroom laptops, or it may be assigned for completion outside of class. The goal is a score of 85 percent correct. When done in class, students show me their score report; when completed at home, students may print or email the score report. On occasion, self-quizzes are projected onto the board and students volunteer to submit a response, or clickers may be used to view each student's response. There are many options to utilize this resource.
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]	Student clickers	**Instructional Activity:** Students use clickers to respond to a set of conceptual questions dealing with hypothetical situations in which various factors such as launch angle, height, and velocity are changed. Students must determine how these changes affect the horizontal displacement, maximum height, and flight time. No calculators are allowed, so I can evaluate the students' conceptual understanding.

I walk about the room listening to students' discussions and conclusions to assess understanding of the concepts involved. For additional practice, a similar task may be given to students who are having difficulty with the task; I may also pair a struggling student with one who gets it to facilitate peer teaching.

When completed in class, I view the score reports and aid students who demonstrate misunderstanding before the student attempts a second set. When completed at home, students email me their scores, and depending on the scores, I may take additional time in class to reteach particular aspects of horizontal launches.

The toughest question for students is how doubling the launch height affects the horizontal displacement. The initial answer is often that the projectile will travel twice as far, which is incorrect. Doubling height increases flight time by root two which increases horizontal displacement by root two.

Guiding Questions: ▼ Why is knowledge of vectors and component calculation vital to understanding two-dimensional motion? ▼ How are the kinematics equations applied to objects experiencing motion in two dimensions? ▼ How do variables such as launch angle, velocity, and altitude affect the maximum height and range of a launched projectile? ▼ What do we mean when we say that the horizontal motion of a projectile is independent of its vertical motion?

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]	Student clickers **Web** "3.5 Initial Velocity Components"	**Instructional Activity:** This Web-based simulation reinforces calculation of the initial launch velocity components. This activity could be used for whole-group questions, with students responding with clickers, or it could be assigned as homework.
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]	Projectile launcher, target, metersticks	**Instructional Activity:** After I lead a discussion on projectiles launched at an angle, students working in small groups use the launcher and calculate the horizontal location. Depending on the time available, this activity could be done with projectiles launched from the ground at various assigned launch angles or from different launch elevations. Before the students attempt the lab from an elevated launch position, I lead them through the steps to calculate flight time for an elevated launch. This particular calculation requires several steps and there are several ways to accomplish it. After working through a few word problems of this nature, students are ready to perform the lab.
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]	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Rock Throw—Maximum Heights"	**Formative Assessment:** In this task, students rank, according to maximum height, six rocks that have been launched with varying velocities but equal inclinations. Without calculating, students should be able to compare vertical components of the launch velocity and base their answers on that variable. I walk around the classroom listening to student discussions and providing verbal prompts when needed. Groups then compare their rankings and justify their conclusions.

This activity allows students repetitive attempts to attain mastery of the mathematics of vector components.

Due to the low ceilings in my classroom, we conduct this lab in our school's main entrance, making this the type of activity that is a great recruiting tool for AP Physics.

I conclude the activity by identifying and correcting any misconceptions. I always have an additional ranking task on hand in case the majority of students need additional practice, or I may give it to a few individual students who need a little extra exposure to a particular concept.

Kinematics in Two Dimensions

(continued)

Guiding Questions: ▼ Why is knowledge of vectors and component calculation vital to understanding two-dimensional motion? ▼ How are the kinematics equations applied to objects experiencing motion in two dimensions? ▼ How do variables such as launch angle, velocity, and altitude affect the maximum height and range of a launched projectile? ▼ What do we mean when we say that the horizontal motion of a projectile is independent of its vertical motion?

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]	Teacher-produced problem set: angle launches	**Instructional Activity:** Using QUEST, I create a problem set with projectiles launched at an angle, both from the ground and from an elevated launch position. The problem set may be printed as a handout and assigned for homework, or it may be assigned online, in which case each student works with varying parameters. As a handout, students turn them in to either be graded by me or discussed in class. When completed online, QUEST sends a score report to me. I use the score results to determine if additional time is needed on the calculations involving angle launches.
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]	Graph paper, colored pencils	**Instructional Activity:** Working in groups (or individually as a homework assignment), students are assigned an initial velocity and a pair of complementary angles; they make a scaled motion graph of both launches on the same axis. Calculations of maximum height, flight time, and range are to be shown. Upon completion, I ask if anyone noticed anything peculiar about their launches. Then, I ask students who calculated equal ranges to stand. Students who are standing assist those who are seated until everyone has successfully calculated equal ranges. Students discover that complementary launch angles will result in equal range but varying height and flight times.

Kinematics in Two Dimensions

(continued)

Guiding Questions: ▼ Why is knowledge of vectors and component calculation vital to understanding two-dimensional motion? ▼ How are the kinematics equations applied to objects experiencing motion in two dimensions? ▼ How do variables such as launch angle, velocity, and altitude affect the maximum height and range of a launched projectile? ▼ What do we mean when we say that the horizontal motion of a projectile is independent of its vertical motion?

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] 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]	Teacher-produced unit assessment	**Summative Assessment:** Students take a unit test consisting of multiple-choice conceptual questions and free-response questions. This test will also include a question in which students have to design an experiment, such as determining a table's height without directly measuring it or the maximum height for a golf shot or football punt. The free-response questions assess the students' mastery of vector mathematics and the use of the kinematics equations, while the conceptual section focuses on projectile motion from a nonmathematic approach. Calculators are not allowed on the conceptual portion of the test, requiring students to think and respond conceptually as opposed to plugging in values and relying on equations to draw a conclusion.

All of the guiding questions in this unit are addressed in this assessment.

Unit 3: Newton's First Law and Equilibrium

Laboratory Investigations:

- Resolution of Forces
- Free-Body Diagrams and Equilibrium
- Coffee Filter Drop (Terminal Velocity)

Estimated Time:

3 weeks

Guiding Questions: ▼ What is Newton's first law and how does it explain static equilibrium? ▼ How is knowledge of the net force essential to understanding an object's constant velocity? ▼ How do free-body diagrams assist in problem solving for Newton's laws of motion?

Learning Objectives	Materials	Instructional Activities and Assessments
Describe a force as an interaction between two objects and identify both objects for any force. [LO 3.A.3.3, SP 1.4] Articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored. [LO 3.G.1.1, SP 7.1]	Knight, Jones, and Field, Chapter 4: "Forces and Newton's Laws of Motion" **Online video** "Brian Cox Explains the Forces of Nature"	**Instructional Activity:** The first 2 minutes of this interesting video explain the electromagnetic nature of contact forces. The opening scenes depict a Rube Goldberg–type apparatus involving many different kinds of forces that will be discussed during this unit. In a follow-up discussion, students list as many forces as they can recall. This serves as the introduction to the forces unit. Be sure to specifically introduce the fundamental forces and the context in which each of these is most prevalent.
Make claims about various contact forces between objects based on the microscopic cause of those forces. [LO 3.C.4.1, SP 6.1] Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [LO 3.C.4.2, SP 6.2]	**Online video** "Forces and Newton's Laws"	**Instructional Activity:** I assign "Forces and Newton's Laws" for homework as a prelesson activity. This 20-minute video does an excellent job of introducing Newton's laws of motion, as well as linking the three laws to one another. Students could either make a list of follow-up questions for class discussion, or they could listen for answers to several questions posted by me.
Challenge a claim that an object can exert a force on itself. [LO 3.A.3.2, SP 6.1]	Student clickers	**Instructional Activity:** I emphasize to students that forces are interactions between two or more objects — an object cannot exert a force upon itself. During this interactive lecture, students categorize forces as either *contact* or *field* forces. The question of whether two objects can really be in contact is introduced by students discussing the meaning and implications of that statement. The atomic nature of contact and force are revisited at this time.

I like to foreshadow here and have students think about why an electron attracts a proton; students will first guess that it's because of opposite charges. I then ask if the force between the Earth and the sun is analogous to the force between the electron and proton.

The graphics in this video are superb and will pique the curiosity of technology-focused students. This video could be assigned for viewing at home as a prelesson activity prior to the first day of this unit.

An interactive lecture *means that students frequently use their clicker devices to respond to my prompts. This addresses the instructional goals of keeping students engaged as well as instantaneous assessment of understanding.*

Newton's First Law and Equilibrium

(continued)

Guiding Questions: ▼ What is Newton's first law and how does it explain static equilibrium? ▼ How is knowledge of the net force essential to understanding an object's constant velocity? ▼ How do free-body diagrams assist in problem solving for Newton's laws of motion?

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]	Spring scales, protractors, unknown masses, 11" × 17" white paper	**Instructional Activity:** This activity is conducted as a way to introduce the vector nature of forces. Students suspend an unknown mass between two spring scales, forming a *y*-shape. The white paper is taped to the wall behind the suspended apparatus. Students sketch their forces and show all of their calculations on this piece of paper, which will remain attached to the wall for several days as reference. Once the students trace the three forces acting on the suspended mass, they have created the free-body diagram for this activity. By measuring the forces on the spring scales and measuring the angles formed, students calculate the unknown mass and then calculate percent difference with the actual mass.
Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [LO 3.B.2.1, SP 1.4, SP 2.2]	Several small boxes, cords, inclined plane	**Instructional Activity:** Following the previous lab, I introduce the concept of a free-body diagram. Students refer to their diagrams from the lab and think about how force vectors can be drawn for any situation. Sketches of several common physics situations are shown, and the appropriate labels and terms are explained. I provide a chart of the most commonly used symbols. Then, students rotate through several stations and construct a free-body diagram for each situation. This activity may include a box at rest on a horizontal surface or on a carpeted incline, a box suspended by a single cord or multiple cords, a box pulled by a rope at an angle, etc. A note card may be used to describe an object's state of motion.
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]	Student clickers, several boxes, cord	**Instructional Activity:** Newton's first law is introduced at this time, as well as the term *equilibrium*. Students use the clickers to calculate the net force acting on several objects and make predictions of the force needed to achieve equilibrium. A variety of one-dimensional objects are shown, and each has two or more forces acting on it.

Newton's First Law and Equilibrium

(continued)

Guiding Questions: ▼ What is Newton's first law and how does it explain static equilibrium? ▼ How is knowledge of the net force essential to understanding an object's constant velocity? ▼ How do free-body diagrams assist in problem solving for Newton's laws of motion?

Learning Objectives	Materials	Instructional Activities and Assessments
	Wooden hoop, flat-topped marker, 500 mL flask	**Instructional Activity:** I perform an inertia demonstration. There are several popular ones: the vertical hoop, pulling an attached string slowly then rapidly, snatching a tablecloth from under dishes, etc. Inertia demos can easily be located online. My favorite is the hoop demo in which a 12-inch wooden cross-stitch hoop stands vertically on top of a 500 mL flask. A flat-topped marker is balanced on top of the hoop. I quickly swipe the hoop aside and the students see the marker fall straight down into the flask. With the hoop demo, allow time for several students to try.
Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [LO 3.B.2.1, SP 1.4, SP 2.2] 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]	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Two Different Blocks and a Pulley—Net Force"	**Formative Assessment:** In this ranking task, students must consider six situations of masses hanging on either side of a pulley (Atwood-machine style). Students rank the six according to net force acting on the system. An extension of this is to have students state the mass needed to achieve equilibrium. Students work independently for 4 minutes and with their lab group for an additional 2 minutes. Groups share their results with the whole class and justify their claims based on supporting evidence. Typically, Atwood machines are investigated during Newton's second law; here they are used as an example of Newton's first law, since the forces are balanced.
		Formative Assessment: Using the same station setup from the free-body diagram activity described earlier, students rotate among the stations; at each one they calculate the forces needed to maintain equilibrium. For the box on the carpeted incline, what friction force is needed to hold the box on the plane? Or for a suspended block, what tension is needed in the rope to lift it at a constant velocity? Students reveal the answers at each station to self-assess their calculations. As an extension, I may include one setup with a floating object to see if students can apply the equilibrium concept to an unfamiliar topic such as buoyancy (this is not specifically assessed in the Physics 1 curriculum).

The trick is to grab the inner edge of the hoop rather than the outer edge. Grabbing the outer edge causes the marker to jump up into the air and miss the flask.

I listen and respond to the student discussion, provide feedback, and decide if additional practice time or discussion is needed based on students' comments.

This station is a great way to assess students' understanding of the concept of, as well as the mathematical approach to, balanced forces. I ask each student one question as I visit each station and provide direct feedback on their responses. Depending on how students respond, I may use an additional day of instruction and practice prior to the quiz that follows this activity.

Newton's First Law and Equilibrium

(continued)

Guiding Questions: ▼ What is Newton's first law and how does it explain static equilibrium? ▼ How is knowledge of the net force essential to understanding an object's constant velocity? ▼ How do free-body diagrams assist in problem solving for Newton's laws of motion?

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, SP1.1] Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [LO 3.B.2.1, SP 1.4, SP 2.2] 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]	Student clickers	**Instructional Activity:** In this interactive lecture, students refer to the actions of a skydiver to discuss both the presence and absence of a net force. A basic understanding of Newton's second law is needed to complement the first law. The actions of the skydiver allow for both laws to be discussed. As I progress through the lesson, students are asked to identify which law, first or second, is apparent the moment the skydiver exits the plane, a few moments later, when she reaches terminal velocity, etc. The use of clickers ensures that each student is responding. The principles of terminal velocity and drag are also explained here.
	Web "2.1.2 Qualitative Questions: Skydiver"	**Formative Assessment:** In this ActivPhysics simulation, students are asked two questions regarding drag force and gravitational force for a descending skydiver.
	Vernier Motion Detectors, basket-type coffee filters	**Instructional Activity:** Using motion detectors, each lab group drops an assigned number of basket-type coffee filters. The velocity-time graphs are printed and displayed for the whole class to compare and analyze. Each group must describe what is shown by each segment of the graph and compare their graphical results with at least two other groups. Students justify their claims about the graph based on their analysis of the velocity-time graph.

I walk through the classroom listening to responses as a way to gauge understanding and to provide feedback directly to students. Or this could be projected to the whole class, with students discussing aloud their responses and both other students and I providing feedback.

In this investigation, I am concerned with a qualitative approach instead of a quantitative one. Will one or six filters reach terminal velocity first? Why? Which one has a lower value for terminal velocity? Can students transfer these thoughts to the operation of a parachute?

Newton's First Law and Equilibrium

(continued)

Guiding Questions: ▼ What is Newton's first law and how does it explain static equilibrium? ▼ How is knowledge of the net force essential to understanding an object's constant velocity? ▼ How do free-body diagrams assist in problem solving for Newton's laws of motion?

Learning Objectives	Materials	Instructional Activities and Assessments
	Teacher-produced problem set: Newton's first law	**Formative Assessment:** I create a problem set pertaining to Newton's first law and static equilibrium. After several days of practice with a lab-based approach to Newton's first law and equilibrium (in the preceding activities), the mathematical approach follows. This set of word problems begins with relatively simple setups of objects being acted upon by two forces, and it progresses to situations including three or more forces. This is assigned for homework, and during the in-class review randomly selected students write their solutions on the board. I make no corrections, but students may challenge a posted solution and provide their own reasoning. I act as a moderator and guide students toward the correct solution if a correct solution cannot be attained by the students within an appropriate time.
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 1.4, SP 2.2]	Teacher-produced unit assessment	**Summative Assessment:** I create a test consisting of three sections: conceptual multiple-choice questions, mathematical free-response questions, and several questions requiring the student to draw a correct free-body diagram. The role of the free-body diagram will be emphasized on certain portions of this test, as will the concept of static equilibrium, motion at a constant velocity, and the nature of the four fundamental forces. The mathematical questions will require students to calculate forces necessary to establish equilibrium.

Students need practice communicating their ideas on why a particular approach is correct or not. This exercise also reinforces noncombative corrections of their peers. I determine whether additional class time is needed with this concept based on the solutions posted on the board and the ensuing challenges.

All of the guiding questions in this unit are addressed in this assessment.

Unit 4:

Newton's Second Law and Acceleration

Laboratory Investigations:

- Factors Affecting Acceleration
- Inertial vs. Gravitational Mass
- Apparent Weight
- Dragging a Shoe
- Net Force
- Newton's Second Law
- Friction, Inclination, and String Tension

Estimated Time:

3 weeks

Guiding Questions: ▼ How does the presence of a net force determine the acceleration of an object? ▼ What is the nature of friction and how does it factor into an object's acceleration? ▼ How can an Atwood's machine be used to calculate the acceleration of gravity?

Learning Objectives	Materials	Instructional Activities and Assessments
Re-express 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]	Student clickers	**Instructional Activity:** To transition from Newton's first law to Newton's second law, the free-body displays are again placed around the classroom. Using clickers, students indicate their solutions to a few calculations of forces need to establish equilibrium. An extending question is posed as to what would happen if a particular force were increased or decreased. Students enter their responses. The response that the object would accelerate should occur. Students calculate the net force, acceleration, or both, and enter responses with the clickers.
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] Apply $F = mg$ 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]	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Forces on Objects on Smooth Surfaces—Speed Change"	**Instructional Activity:** After I lead a discussion on Newton's second law, emphasizing the role that net force and mass play on the acceleration of an object, students work in small groups on this ranking task. The goal is to rank the situations according to changes in velocity. Pairs of forces acting in opposite directions are shown, requiring a quick mental calculation of net force before the task can be completed.
	Student clickers, free-body diagrams	**Formative Assessment:** Several free-body diagrams with numerical values included are projected onto the board, and students use their clickers to answer questions of net force and acceleration. This provides me with holistic information regarding the students' depth of understanding.
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]	Sliding blocks, metersticks, spring scales, stopwatches, slotted masses, easel pad	**Instructional Activity:** With the materials provided, students design an activity to demonstrate the factors that affect the acceleration of an object on a horizontal surface. Each group is provided one sheet of easel-pad paper folded into fourths. On the paper, students must sketch and explain their activity and the various trials that were conducted in these quadrants. The papers are then displayed in the classroom and referenced throughout the unit.

This activity serves as a preinstruction assessment, to some extent, by allowing me to assess how easily (or not) students can transition their prior understanding to the effects of net forces. The situations initially are simple and progress in complexity until I have discovered the starting point for the next lesson.

Along with traditional horizontal motion, I include the vertical axis with regard to lifting and lowering an object. I point out to students that horizontally the weight is not factored into the calculation of net force; however, weight plays a significant role in the calculation of net force for an object being moved vertically.

If students demonstrate a lack of understanding, I may use an extension lesson in which students volunteer to explain their reasoning. In the case of widespread confusion, I may reteach the appropriate content.

Newton's Second Law and Acceleration

(continued)

Guiding Questions: ▼ How does the presence of a net force determine the acceleration of an object? ▼ What is the nature of friction and how does it factor into an object's acceleration? ▼ How can an Atwood's machine be used to calculate the acceleration of gravity?

Learning Objectives	Materials	Instructional Activities and Assessments
	Web "Net Force Quiz"	**Formative Assessment:** This online quiz could be projected onto a SMART Board for students to respond with clickers, or students could individually access it online. I may have students submit the answer to one or two questions, via clickers, during the last moments of class and then continue to complete the assignment at home.
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] 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]	Unopened soda cans (diet and regular)	**Instructional Activity:** After mastering the concept of net force, a special focus on the concept of mass versus weight is needed, and a further investigation of gravitational mass versus inertial mass is also appropriate. One way to differentiate inertial mass is to have a pair of unopened cans of soda on each lab table, one regular and one diet. Lab-table groups must decide which has a greater mass and present the rationale for their decision.
	Web "Inertial vs. Gravitational Mass"	**Instructional Activity:** This online lesson does a good job of explaining gravitational mass versus inertial mass and the methods for determining both. This is an important activity, as it provides background information for the next activity — in which students design a quick experiment to measure the gravitational and inertial masses.
	Several bathroom-type scales	**Instructional Activity:** Students are quick to say that a person's weight changes with altitude because of varying values for the acceleration due to gravity. To extend students' thinking, I ask: *What happens to a person's weight in an accelerating environment?* Have students stand on scales and pretend they are riding in an elevator. At first the elevator is at rest while at the lobby. Next, students simulate their motion as the elevator accelerates upward. I ask questions such as the following: *Does the reading on the bathroom scale change? What about during the time of constant velocity as the elevator smoothly travels upward, as the elevator comes to a stop at the penthouse, or as the elevator begins to accelerate downward?*

When completed in class, I monitor students' progress and provide verbal feedback; if completed for homework, I provide written feedback the next day. If additional review time is needed, I provide an additional set of problems. If students self-assess that they have mastered the concept, they should move on to the next concept.

The natural response is to place one can in each hand and move the hands up and down. The can that seems more difficult to raise and lower has a greater inertial mass. I ask the students, Would this same demo work well with really light objects like cotton balls and ping pong balls?

To extend the thinking process, students can predict the velocity-time graph for this elevator ride. One of the ah-ha moments is the realization that they don't feel the force that they exert on others; they can only feel forces that act on them. As you stand, you feel the floor pushing up on you. On a bathroom scale, the scale displays the force that the floor exerts upward (the normal force) on the soles of your feet.

Newton's Second Law and Acceleration

(continued)

Guiding Questions: ▼ How does the presence of a net force determine the acceleration of an object? ▼ What is the nature of friction and how does it factor into an object's acceleration? ▼ How can an Atwood's machine be used to calculate the acceleration of gravity?

Learning Objectives	Materials	Instructional Activities and Assessments
		Instructional Activity: After the demonstration of apparent weight in the preceding activity, I introduce the calculations of apparent weight using the same elevator examples. These calculations reinforce the thought process of identifying the component forces that make up the net force and how the direction of the acceleration determines how the forces are arranged in the equation.
	Vernier Force Sensors, pulley, string, laptops	**Instructional Activity:** If Vernier probes are available, I have students design a lab to explore apparent weight for an accelerating system; this is analogous to the elevator problems.
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]	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Person in an Elevator Moving Upward—Scale Weight"	**Formative Assessment:** This ranking task depicts six situations in which a person stands on a bathroom scale inside an elevator while it accelerates upward or downward; students rank the situations according to the apparent weight felt by the passenger. Student groups stand and share their rankings, and I encourage students to explain their reasoning based on the previous day's elevator activity.
	Athletic shoes, spring scales, felt pieces, mass sets (either hooked or slotted)	**Instructional Activity:** In this interactive lecture the frictional force is introduced, including the coefficient of friction. As the concepts are presented, student groups drag a shoe across their tabletop using a spring scale; they then place a piece of felt under the shoe and drag again, noting differences in the applied force. Eventually, mass is added to the shoe and the activity is repeated. I refer to these actions and results as the lesson progresses. The equation using the coefficient of friction is introduced here.

I also have students think about other real-world situations in which they seem to have a different weight. They usually respond with "while swimming" or "in a roller coaster loop." A few minutes could be devoted to explore apparent weight with submerged or floating objects.

I use the force sensors and pulley to allow the "elevator" to accelerate both up and down and have a graphical display of the apparent weight. This lab activity is easy for students to complete and is an excellent reinforcement.

Students or groups needing additional explanation may be paired up with a peer instructor for several minutes of review. I walk throughout the classroom verifying that all students are confident in their understanding of apparent weight. If needed, a second ranking task may be used for additional practice.

The term normal force *is also introduced and explained conceptually, with calculations to follow on subsequent days.*

Guiding Questions: ▼ How does the presence of a net force determine the acceleration of an object? ▼ What is the nature of friction and how does it factor into an object's acceleration? ▼ How can an Atwood's machine be used to calculate the acceleration of gravity?

Learning Objectives	Materials	Instructional Activities and Assessments
	Easel pad, markers	**Instructional Activity:** Students brainstorm and list actions in which friction is desirable and undesirable. For the instances when friction is not desired, what steps can be taken to lessen its effect? The ideas are written (perhaps sketched) on easel pads, and each group shares its most original example. If time allows, these are hung on the walls and students take a "museum walk," offering critiques, perhaps voting on most creative, etc.
		Instructional Activity: Normal force is next addressed mathematically. It was conceptually explored previously with apparent weight, bathroom scales, and elevators. The four cases for calculating normal force are presented here: box on a horizontal surface, box with upward-acting applied force (wagon), box with downward applied force (lawnmower), and box on an incline. Examples of these four cases are displayed throughout the classroom as visual support. For each case, students discuss how the normal force would be calculated. Volunteers write their guesses on the board, and responses are compared and modified. Once the four equations for normal force are developed, numerical values are provided for the component forces and students calculate the values for the normal force.
		Formative Assessment: With the displays from the preceding activity still up, I pose conceptual questions involving no calculations, such as the following: *If the inclination is increased, how is normal force affected, and how does this affect the acceleration? If a second box is stacked on top of the first, what changes result?* After several minutes of discussion, students break into groups, with one group per display. Each group presents to the class three changes that could be made to their display and explains what would be the resulting effects to the system.

Examples of desirable friction: writing with a pencil, nails remaining in the walls, and athletic-shoe traction. Examples of undesirable friction: moving parts of an engine and athletic events requiring speed such as swimming, sprinting, and skiing.

Students have a difficult time with the idea that the normal force can be calculated in four different ways. The majority want to use mass times the acceleration of gravity (m x g) *for each normal-force calculation.*

With the second portion of this activity, I serve as the moderator and help guide students in their qualitative exploration of "what would happen if I did this?" I provide direct feedback to students' predictions. Based on the number of student queries and any misunderstandings, I am able to discern which students may need additional assistance.

Newton's Second Law and Acceleration

(continued)

Guiding Questions: ▼ How does the presence of a net force determine the acceleration of an object? ▼ What is the nature of friction and how does it factor into an object's acceleration? ▼ How can an Atwood's machine be used to calculate the acceleration of gravity?

Learning Objectives	Materials	Instructional Activities and Assessments
	Dynamics carts and dynamics tracks, spring scales, metersticks, stopwatches, air track, bottle of viscous liquid, steel bearing	**Formative Assessment:** This lab on net force lasts several days, as students rotate through the different stations. At each station, students first calculate the acceleration that is expected if no friction were present and then perform the activity and measure the actual acceleration. Next, they calculate the frictional force and possibly the coefficient of friction. Stations mimic the four possibilities for normal force. One station involves a large graduated cylinder containing some sort of clear, viscous liquid (e.g., shampoo, corn syrup) and a steel bearing or heavy marble; at this station, students calculate the drag (frictional) force that the liquid exerts. Be creative: incorporate an air track into one of the stations if available or maybe a ramp that is partly smooth and then rough.
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]	Teacher-produced problem set: normal force and friction	**Instructional Activity:** I give students a set of practice problems to provide ample opportunities for them to calculate the normal force, frictional force, net force, and acceleration for each of the four normal-force calculations described earlier.
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 6.4, SP 7.2]	Video camera, PowerPoint or SMART Board	**Instructional Activity:** Student groups design a virtual experiment involving real-world situations to demonstrate Newton's second law. There is a lot of room for student interpretation here (e.g., drag car races, spacecraft launch, tow trucks, cranes, theme-park rides). Each group includes either photos of their virtual experiment or a short video clip. Groups present to the whole class. Included in the presentation is at least one example of appropriate calculations.

I typically allow 25 minutes per station. As the lab progresses, I roam the classroom, visiting lab groups and discussing observations, calculations, and conclusions to provide feedback directly to students. For students who are still struggling with the concept of normal force or friction, I pair them with table leaders or assist them myself.

Newton's Second Law and Acceleration

(continued)

Guiding Questions: ▼ How does the presence of a net force determine the acceleration of an object? ▼ What is the nature of friction and how does it factor into an object's acceleration? ▼ How can an Atwood's machine be used to calculate the acceleration of gravity?

Learning Objectives	Materials	Instructional Activities and Assessments
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] Apply $F = mg$ 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]	Smart pulleys suspended from ceiling, light string, hooked masses, stopwatches, metersticks	**Instructional Activity:** Atwood machines are introduced to students through an inquiry-based activity. Each lab group is provided one Atwood machine. Initially the device is at equilibrium and students make observations about the masses being balanced. Adding a small mass to one side, students observe the acceleration of the system. Repeated trials with increasing mass are performed for several minutes. Students then work in pairs or small groups and use metersticks and stopwatches to measure the acceleration of each mass of the system. Whole-class discussion follows, where students share their data-collection strategies and results. If students sketched the setups and recorded how much mass was on each side of the apparatus for each trial, they could calculate the accelerations using Newton's second law as a homework assignment.
	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Two Different Blocks and a Pulley—Tension"	**Instructional Activity:** This ranking task shows six Atwood machines with varying masses on each side, and students rank the figures on the basis of the tension in the string.
	PASCO Scientific (for *Model ME-9435A and ME-9429A*), Experiment 6: "Newton's Second Law"	**Formative Assessment:** Following lessons on the modified Atwood machines, students perform the PASCO lab. Accelerations are calculated using kinematics and Newton's second law. Percent difference is used to compare the values. This lab assumes a frictionless surface. The lab guides students through two methods to calculate and/or measure the acceleration of a system. Students perform the calculation first and then compare the value that was determined during the lab activity with the calculated value. A small percent difference reinforces the students' computational and lab practical skills.

Students are initially mesmerized as the masses move with constant velocity when given a small initial push. The curiosity grows as the masses are added and the system accelerates. The idea is for students to notice that the acceleration of the rising mass equals that of the descending mass. This activity reviews kinematics and allows for a nice transition to calculation of the acceleration using Newton's second law, and it serves as the introduction to tension.

I receive information about students' learning as I walk among the lab groups asking questions. I provide feedback as they answer questions from their peers, as well.

Newton's Second Law and Acceleration

(continued)

Guiding Questions: ▼ How does the presence of a net force determine the acceleration of an object? ▼ What is the nature of friction and how does it factor into an object's acceleration? ▼ How can an Atwood's machine be used to calculate the acceleration of gravity?

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 6.4, SP 7.2]	Dynamics tracks, string, spring scales, friction blocks, inclinometers	**Instructional Activity:** Using inclined dynamics tracks, spring scales, and friction blocks, student lab groups design a lab that demonstrates the effect that friction and inclination have on the tension in a string. When complete, students must get approval from me regarding the validity of the procedures.
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] Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [LO 3.B.2.1, SP 1.4, SP 2.2] 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]	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Moving Car and Boat Trailer—Force Difference"	**Instructional Activity:** After I lead a discussion on Newton's third law, this ranking task has students rank six figures of cars pulling boat trailers, according to the forces that the cars exert on the boat trailers compared to the forces that the boat trailers exert on the cars.
	Teacher-produced problem set: Atwood machines	**Instructional Activity:** Students complete a problem set focusing on Atwood machines and objects in contact. Papers are peer graded within the table group. This allows students to converse about why a certain problem-solving approach is correct, efficient, or misguided. I ask volunteers to write the solution on the board if general questions arise or clarification is still needed.
	Teacher-produced unit assessment	**Summative Assessment:** This test may take two class periods if all of Newton's laws are assessed. Multiple-choice questions, drawing free-body diagrams, and free-response questions are included. A significant portion of the test requires students to draw appropriate free-body diagrams and then make calculations of various forces and accelerations. Apparent weight and its relationship to normal force while in an elevator is assessed. This test also has an experimental-design component or a data-analysis section.

This is a small peek at Newton's third law, which will be investigated thoroughly in the next unit.

All of the guiding questions in this unit are addressed in this assessment.

Unit 5: Two-Mass Systems and Newton's Third Law

Laboratory Investigations:

- Atwood's Machine
- Modified Atwood Machines
- Third Law in the Real World

Estimated Time:

3 weeks

Guiding Questions: ▼ What considerations must be made when a system is composed of two or more objects? ▼ Why is the Atwood machine an exemplar for systems of masses? ▼ What are action-reaction force pairs? And do they cancel each other?

Learning Objectives	Materials	Instructional Activities and Assessments
Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively. [LO 4.A.1.1, SP 1.2, SP 1.4, SP 2.3, SP 6.4]	Knight, Jones, and Field, Chapters 4 and 5: "Forces and Newton's Laws of Motion" and "Applying Newton's Laws" Two equal masses placed side by side, two equal masses joined by a cord	**Instructional Activity:** I present two questions to students: *How do Newton's laws apply to a system composed of two or more objects?* and *How are systems of two or more objects treated mathematically compared to single objects?* Students discuss the questions in small groups to develop a working model. The simplest mass systems are two equal-mass boxes joined by a rope and/or two equal-mass boxes adjacent to each other. If a force pulls the two joined boxes horizontally or pushes the adjacent boxes, what happens to the system? The system accelerates. Through guiding questions, the students realize that it is actually the center of mass that is being accelerated by the actions of the net force.
Make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. [LO 4.A.2.1, SP 6.4]	Tennis racket, baseball bat, broom, serving spoon, violin/ guitar, hammer, large spoon for cooking	**Instructional Activity:** Several of the listed items are placed on the lab tables, and students first try to identify where their centers of mass are located. Typically, some student will have prior knowledge and will relate center of mass to a balance point. Once students see a peer balancing an object, the working definition of center of mass spreads throughout the classroom. To extend this, I ask a student to flip the spoon or tennis racket into the air and catch it. Have students discuss how the ends of the object moved as it rotated and how the center of mass moved as the object rotated.

Even though no calculation of center of mass is required in Physics 1, I like to have students think about the location of the center of mass, especially for objects of uniform distribution (e.g., meterstick, bowling ball, doughnut); then we make predictions for a few common objects (e.g., broom, hammer, baseball bat). To complement this first discussion, I display two identical boxes joined by a string and ask for the probable location of the center of mass.

Two-Mass Systems and Newton's Third Law

(continued)

Guiding Questions: ▼ What considerations must be made when a system is composed of two or more objects? ▼ Why is the Atwood machine an exemplar for systems of masses? ▼ What are action-reaction force pairs? And do they cancel each other?

Learning Objectives	Materials	Instructional Activities and Assessments
Predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center of mass motion of the system and is able to determine that there is no external force. [LO 5.D.3.1, SP 6.4] Model verbally or visually the properties of a system based on its substructure and to relate this to changes in the system properties over time as external variables are changed. [LO 1.A.5.1, SP 1.1, SP 7.1] 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] Create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system. [LO 4.A.2.3, SP 1.4, SP 2.2] Apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system. [LO 4.A.3.1, SP 2.2]	Atwood machines	**Instructional Activity:** Atwood machines are hung from the ceiling for each lab group. Initially, the two hanging masses are equal. Students are encouraged to play around with the Atwood machines and to discuss all physics-related observations that are made. Additional time is allowed for observations when the masses are unbalanced. Students add a penny to one side of the device, and they make observations and draw conclusions about the center of mass of the system. I listen to their comments and respond with additional questions to consider, and I challenge any misconceptions the students articulate during the activity.
	Student clickers	**Instructional Activity:** After the qualitative consideration of the Atwood machine, students are introduced to the mathematics of this two-mass system when a net force is present. As the equations are presented and explained, students use clickers to submit their numerical responses. Once the students are proficient at calculating the acceleration of the system, the next activity blends the calculation of that acceleration with the idea of center of mass.
	8½" × 17" paper or easel pad	**Instructional Activity:** Students working individually draw a large Atwood machine. Values for m_1 and m_2 must each be higher than 25 kg, with the difference between them being between 2–5 kg. On the paper, the calculation for the system acceleration is shown and a dot representing the center of mass is drawn. Once acceleration is known, students determine how much distance exists between the larger mass and the bottom edge of the paper and calculate the time to reach the bottom edge. This time is then divided in fifths, and the students calculate the location of the center of mass for these time intervals and mark the relative position of the center of mass and m_1 and m_2.

This is the second time that students have been exposed to Atwood machines. The first was with Newton's first law and equilibrium.

Have students elaborate orally on their assumption that the accelerations of the individual objects are equal to the acceleration of the system as a whole. Have them describe what they would observe if the accelerations were not equivalent.

This is best done individually with 8½" × 17" paper so that students may refer to their work later in the unit as the lesson progresses.

Two-Mass Systems and Newton's Third Law

(continued)

Guiding Questions: ▼ What considerations must be made when a system is composed of two or more objects? ▼ Why is the Atwood machine an exemplar for systems of masses? ▼ What are action-reaction force pairs? And do they cancel each other?

Learning Objectives	Materials	Instructional Activities and Assessments
	Appel et al., "Atwood's Machine"	**Instructional Activity:** This lab reinforces the acceleration calculations that students have practiced. It is useful in that graphical data is produced, which further reinforces the role that net force plays in the acceleration of the system.
Use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system. [LO 4.A.3.2, SP 1.4]	Demonstration-size Atwood machine, spring scales, student clickers	**Instructional Activity:** Once students are comfortable with calculating acceleration of an Atwood machine, an interactive discussion of tension in the connecting string takes place. A large Atwood machine is on display in the classroom, with spring scales attached to each side so that the actual tensions may be viewed. Students use their clickers to submit their tension calculations for several possible mass combinations.
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] Create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system. [LO 4.A.2.3, SP 1.4, SP 2.2] Apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system. [LO 4.A.3.1, SP 2.2]	Several modified Atwood machines, student clickers	**Instructional Activity:** The progression from Atwood machine to modified Atwood machine is made with m_1 being on a horizontal surface and m_2 dangling from the pulley, as well as the same setup on an inclined plane. I reinforce the idea that the net force accelerates the center of mass of the system. Free-body diagrams are revisited, as well as the inclusion of friction with coefficients of friction. Several calculations are asked for, and students respond with their clickers.
	Web "2.11 Modified Atwood Machine"	**Instructional Activity:** In this simulation, students work through eight questions involving modified Atwood machines.

This simulation is beneficial in that it also presents conceptual questions to consider along with calculations. The students are able to click an "advisor" button that provides hints for each question.

Two-Mass Systems and Newton's Third Law

(continued)

Guiding Questions: ▼ What considerations must be made when a system is composed of two or more objects? ▼ Why is the Atwood machine an exemplar for systems of masses? ▼ What are action-reaction force pairs? And do they cancel each other?

Learning Objectives	Materials	Instructional Activities and Assessments
	Web Newton's second law quiz	**Formative Assessment:** This online quiz allows students to submit an answer and have it scored immediately to receive feedback. These six questions all include masses joined by strings over a pulley.
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]	Modified Atwood machines, dynamics carts and dynamics tracks, friction blocks	**Instructional Activity:** In this station lab, there are three setups: a frictionless cart (i.e., rolling on its wheels) on a horizontal surface connected by a string over a pulley to a dangling mass, a friction block attached by a string over a pulley to a dangling mass, and a friction block on an inclined plane connected by a string to a dangling mass. At each station, students draw appropriate free-body diagrams, varying both m_1 and m_2, and measure the acceleration and calculate the tension in the joining string.
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]	**Online video** "Systems: Two or More Bodies/3rd Law (Newton's Third Law)"	**Instructional Activity:** In this video, Dr. Lewin introduces the concept of action-reaction forces and Newton's third law. The forces involved with adjacent objects are also diagrammed and explained. Several real-world examples of Newton's third law are mentioned. The video also includes a brief segment of a static-equilibrium problem. This provides a nice review of Newton's first law. While viewing, students listen for answers to several posted viewer's questions. After the video, a whole-class discussion follows.
	Knight et al., *Student Workbook*, 5.7: "Interacting Objects"	**Instructional Activity:** This is a nice conceptual lesson on interacting objects. Students complete this in small groups, individually at home before class, or individually during class.

When completed in class, I view each score report and then provide additional instruction if necessary. If completed at home, the score reports are emailed to me or printed and submitted the next day. Again, I view the reports to identify struggling students or particular topic objectives that need reteaching. I may give struggling students a handout of additional problems, with several completed as examples, or peer tutors may be assigned.

For the frictionless-cart assembly, students could be asked to calculate the acceleration of the system and compare that to the measured acceleration.

I may post several questions for students to particularly listen for, or the class might be asked to pay attention in order to recall a particular demo that is performed.

Two-Mass Systems and Newton's Third Law

(continued)

Guiding Questions: ▼ What considerations must be made when a system is composed of two or more objects? ▼ Why is the Atwood machine an exemplar for systems of masses? ▼ What are action-reaction force pairs? And do they cancel each other?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] Use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system. [LO 4.A.3.2, SP 1.4]		**Instructional Activity:** Several displays of adjacent objects are placed throughout the classroom. Initially, students respond to conceptual questions posed by me, such as identification of action-reaction forces, followed by calculations of acceleration of the two-mass system and the forces between the objects. I ask volunteers to draw appropriate free-body diagrams on the board for each setup.
	Knight, Jones, and Field, Chapter 5, end-of-chapter problems **Web** "Combining Kinematics and Dynamics" "Distinguishing 2nd and 3rd Law Forces" "Ropes and Pulleys in Static Equilibrium"	**Formative Assessment:** As students prepare for a comprehensive test on Newton's three laws of motion, use these four self-quizzes as opportunities for review.
		Summative Assessment (Option 1): Student groups design an experiment to demonstrate Newton's third law. Students create a 2-minute video of their device (or prepare a poster presentation), including an explanation of the physics concepts and the mathematics that are involved. I distribute the topics, with no more than two groups using the Atwood machine as their device (the same for modified Atwood machines and adjacent boxes).

Student success is monitored as I walk throughout the classroom to assess preparedness and need for additional review. I provide direct feedback to students during their review.

All of the guiding questions in this unit are addressed in this assessment.

Two-Mass Systems and Newton's Third Law

(continued)

Guiding Questions: ▼ What considerations must be made when a system is composed of two or more objects? ▼ Why is the Atwood machine an exemplar for systems of masses? ▼ What are action-reaction force pairs? And do they cancel each other?

Learning Objectives	Materials	Instructional Activities and Assessments
	Teacher-produced unit assessment	**Summative Assessment (Option 2):** I create a test covering all aspects of Newton's third law and interaction of two-mass systems. This assessment contains both noncalculator multiple-choice questions as well as free-response questions. There are significant portions for Atwood machine calculations involving three suspended masses, modified Atwood machines with boxes joined by string, and adjacent boxes. Tensions or forces between the boxes are to be calculated, as well as conceptual-discussion questions about the center of mass.

All of the guiding questions in this unit are addressed in this assessment.

Unit 6: Work and the Conservation of Energy

Laboratory Investigations:

- How Angle of Force Determines the Amount of Work
- Measuring the Spring Constant
- Do Rubber Bands Obey Hooke's Law?
- Work-Energy Theorem
- Energy of a Tossed Ball
- Atwood's Machine and Center of Mass
- Friction on a Sliding Object

Estimated Time:

4 weeks

Guiding Questions: ▼ How is the energy of a system defined? ▼ How is work represented graphically? ▼ What is mechanical energy and what factors affect its conservation?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	Knight, Jones, and Field, Chapter 10: "Energy and Work"	**Instructional Activity:** This is an interactive lecture to address the guiding question: *How is the energy of a system defined?* I project various photos of real-world devices and/or situations, such as an automobile, a mousetrap-powered cart, an oscillating fan, a pot of boiling water, a pole vaulter, etc., and students brainstorm and describe the types of energy present and discuss possible changes in these energy types.
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]	Any kind of sports balls	**Instructional Activity:** Each lab group is given a sports ball. With the ball at rest, students must identify the closed, isolated system. Students then discuss and choose one way in which to change the kinetic or potential energy of their ball. As students explain how their energy change takes place, I guide them toward the idea of an outside force being needed.
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] 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]	**Web** "5.1 Work Calculations"	**Instructional Activity:** Students use an ActivPhysics simulation that takes them through four situations in which work is to be calculated. The situations involve a cable raising and lowering an elevator along an incline, a pendulum swinging, and a skydiver landing in deep snow. The positive or negative nature of the response is also included.
	Student clickers	**Instructional Activity:** After I lead a short discussion of work, its scalar nature, and when work is considered to be positive or negative, students use the clickers to respond to questions regarding whether work done by the environment on the system is positive or negative.

I encourage students to consider questions such as the following: Does the gravitational force do positive or negative work when I lift a crate? When a crate slides down an incline? When a crate is held suspended in midair? When a crate is attached to a rope and swung in a big sweeping arc? *You can also change the perspective and ask the same questions referring to the work done by the person.*

Guiding Questions: ▼ How is the energy of a system defined? ▼ How is work represented graphically? ▼ What is mechanical energy and what factors affect its conservation?

Learning Objectives	Materials	Instructional Activities and Assessments
	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Equal Forces on Boxes—Work Done on Box"	**Formative Assessment:** This ranking task has students consider six crates, each with a force exerted on it. The orientation of the forces varies, as does the magnitudes of the forces and the displacement of the boxes. Without calculators, students must consider the component of the force acting parallel to the displacement, as well as the magnitude of the displacement, as they rank the work done on the box by the applied force. As with all ranking tasks, students work individually for several minutes, then as table groups, and finally whole-class discussion ensues. Each group shares their results.
	Student clickers	**Instructional Activity:** As the quantitative approach to work is presented, students use clickers to submit their responses. The diagrams from the previous ranking task could be used with values for forces and angles added or a new set of boxes and forces could be created to be projected. Examples should include forces applied horizontally, forces applied upward like a wagon handle, and forces applied downward like a lawnmower, forces applied vertically downward, and forces applied parallel to the surface for a box moving along an inclined plane.
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]	Friction blocks, spring scales, 500 g mass, protractor	**Instructional Activity:** Each table is provided a friction block, a spring scale, and a 500 g mass. The goal of this inquiry-based activity is for students to observe how the applied force varies with the angle at which the force is applied, and how this impacts the work being done on the block. The 500 g mass may or may not be used, depending on the curiosity of the group members.
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]	Teacher-produced problem set: work done on an object	**Instructional Activity:** Students complete a problem set focusing on the work done on an object when given information about a force exerted on the object or system through a distance.

If there are various conclusions drawn by different groups, I step in and guide the groups toward the correct response and provide direct feedback to students.

Work and the Conservation of Energy

(continued)

Guiding Questions: ▼ How is the energy of a system defined? ▼ How is work represented graphically? ▼ What is mechanical energy and what factors affect its conservation?

Learning Objectives	Materials	Instructional Activities and Assessments
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 2.2, SP 6.4] 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]	**Web** "Force vs. Displacement Graphs"	**Instructional Activity:** Following a discussion led by me regarding the force-distance curve, students complete the activity online and check their responses as they progress. I walk among the students, asking leading questions and helping students link the graphical approach to the algebraic approach.
	Web "Work Done by a Spring"	**Instructional Activity:** This activity quickly helps demonstrate for students the work done by a spring as the work and energy graphs are displayed.
	Dynamics carts, slotted masses, ruler	**Instructional Activity:** Following a lesson led by me regarding work done by a variable force and the concept of restoring force and spring constant, students use the springs in the PASCO carts and complete an activity designed to measure the spring constant of the springs in the carts. Data includes mass added to the spring and the resulting spring compression. The data is graphed as a force-displacement graph and the slope of the curve is the spring constant.
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] 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 2.2, SP 6.4]	Teacher-produced problem set: $W = 1/2kx^2$	**Instructional Activity:** Students complete a set of problems focusing on work done by a variable force (i.e., spring).

Calculating the spring constant for the dynamics cart is not inquiry based, but it is the first step toward later use of the dynamic carts' springs in the inquiry activities.

Guiding Questions: ▼ How is the energy of a system defined? ▼ How is work represented graphically? ▼ What is mechanical energy and what factors affect its conservation?

Learning Objectives	Materials	Instructional Activities and Assessments
	Rubber bands, rulers, spring scales	**Instructional Activity:** Students, working individually or in small groups, perform a simple activity to construct their own force-displacement graph. Using a rubber band, spring scale, and ruler, students stretch the rubber band in 5 cm increments using the hook of the spring scale to pull. Students record the force for each 5 cm increment. After reaching the maximum stretch of the rubber band, students create a force-displacement graph for the rubber band. In two sentences or less, students summarize the significance of the area under the curve.
	Teacher-produced quiz, student clickers	**Formative Assessment:** Students complete a quiz focusing on calculations of work and interpretations of force-displacement graphs. The quiz responses are entered with clickers, and I can view a real-time chart of each student's response, as well as quickly see what incorrect answer appears in the frequently missed questions.
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] 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, SP1.5] 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]	**Online video** "Conservation of Energy"	**Instructional Activity:** As a way of introducing the work-energy theorem, I show this 29-minute video. The first portion of the video reviews the concept of work as the product of force and displacement, and it extends the content into energy in various forms and the role that work plays in transforming energy into many different forms. Either several questions are posted for students to consider while viewing, or the students are asked to create five viewers' questions that they would like to have answered at the video's conclusion.

This information from the activity allows me to address misconceptions immediately. This also provides immediate feedback to students on how well they understand these concepts.

You may or may not wish to include the work done by a force during circular motion (e.g., the work done by tension for an object on the end of a string being swung in a circular horizontal path).This can be re-emphasized during the unit on circular motion.

Guiding Questions: ▼ How is the energy of a system defined? ▼ How is work represented graphically? ▼ What is mechanical energy and what factors affect its conservation?

Learning Objectives	Materials	Instructional Activities and Assessments
	Student clickers	**Formative Assessment:** Following the video, students use the clickers to submit responses to questions I pose regarding aspects of work and kinetic and potential energy.
	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Bouncing Cart—Work Done by the Barrier"	**Instructional Activity:** This ranking task depicts six spring carts impacting and rebounding from a barrier. The mass as well as the initial and final velocities of the carts are given. Students rank the work done by the barrier on the cart for each situation. Students must consider the changes in velocity in relation to the changes in kinetic energy as they make their guesses. Students work alone for 5 minutes and then compare answers with their table mates for an additional 3 minutes before whole-class discussion.
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] 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] 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] 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]	Student clickers	**Instructional Activity:** Students use clickers with several questions regarding change in kinetic energy. This could serve as the warm-up activity for a particular day. Pairs of initial and final velocities are given. Using only these pairs, students determine if the kinetic energy of the object would increase, decrease, or remain the same. Be sure to include both positive and negative velocity values. Students typically struggle with a negative velocity producing a negative kinetic energy. Emphasize that kinetic energy is a scalar and does not act in a certain direction.

Using carefully selected questions, I can determine which concepts were understood from the video and which need to be reiterated during subsequent instruction.

Work and the Conservation of Energy

(continued)

Guiding Questions: ▼ How is the energy of a system defined? ▼ How is work represented graphically? ▼ What is mechanical energy and what factors affect its conservation?

Learning Objectives	Materials	Instructional Activities and Assessments
	Student clickers	**Instructional Activity:** An interactive lecture is presented in which the work–kinetic energy theorem is expanded to include potential energy. Throughout the lecture, students use the clickers to respond to posed questions and/or calculations. Net work as the means to change the kinetic energy of an object is reviewed; work being the agent of change in the gravitational potential energy is introduced. Several practice problems are introduced, with students calculating and responding. Following gravitational energy, elastic potential energy is also presented, again with sample problems to calculate. At this point, the term *mechanical energy* is introduced as the representative of the total energy of a system.
	Easel pad, markers	**Instructional Activity**: Groups of students are given a piece of easel-pad paper and create a real-world situation that would experience energy transformations, which I provide to them. Examples of transformations could include: work changes kinetic energy, kinetic energy is transformed into gravitational potential energy, elastic potential energy is transformed into kinetic energy, etc. The final example is for one of the forms of energy to be converted into thermal energy. Students then research thermal energy as homework and bring in their example of thermal energy being created.

This activity reinforces the idea that the component of the applied force must be considered. This is also the first opportunity to emphasize that no work is done when the force is applied perpendicular to the displacement.

This activity could include numerical values and be extended an additional day to allow for calculations of values such as mechanical energy or one of the component forms of energy.

Work and the Conservation of Energy

(continued)

Guiding Questions: ▼ How is the energy of a system defined? ▼ How is work represented graphically? ▼ What is mechanical energy and what factors affect its conservation?

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] 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, the student can 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]	Dynamics tracks and dynamics carts, metersticks	**Instructional Activity:** Using the PASCO carts and tracks, students working in small groups demonstrate the transformation of elastic potential energy into gravitational energy. The cart is launched by its own spring up the inclined plane. Students first discuss then calculate the maximum vertical height to which the cart should rise; they then perform the experiment. Discrepancies are discussed. This activity is described in the PASCO lab manual, but I prefer to modify the lab to have students think and plan the experiment on their own.
	Web "A Spring, a Ramp, and a Mass"	**Instructional Activity:** This quick online Physlet demonstrates the lab described in the previous activity and includes energy graphs. Using the cursor allows the student to measure the ramp height and the length of travel, which might be more accurate than the measurements attained in lab, thus providing data more closely in line with what is expected.
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] 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]	Appel et al., "Energy of a Tossed Ball" Motion detectors, several sports balls	**Formative Assessment:** In this lab, a ball is tossed upward while positioned above the motion detector. Data is collected and graphs of distance versus time, velocity versus time, potential energy, and total energy are produced by the students. I question each group about the meaning of the curve on the potential energy graph and total energy graphs. Final graphs are printed, and students write significant points directly on the graphs.
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]		**Instructional Activity:** Students lead a discussion of the role of thermal energy in the work-energy theorem. Depending on the kinds of examples given by the students, the role of thermal energy as a desired outcome or as a form of "wasted" energy is explored. Students list several examples of thermal energy being produced "on purpose" (as with a clothes dryer) and thermal energy being the undesirable outcome of the frictional force doing negative work.

The approach should emphasize the work done by the external force to compress the spring and that work changing first the elastic potential energy of the spring and ultimately the gravitational energy of the cart.

This Physlet could be used for a whole-class demonstration if materials for the previous lab are not available, as a Web lab conducted at home, or as a makeup lab for an absent student.

Feedback occurs as I visit each group, answering any questions from the group members. If any group members are struggling, a peer may be brought into that lab group to help, or I may spend a few moments providing clarification.

Guiding Questions: ▼ How is the energy of a system defined? ▼ How is work represented graphically? ▼ What is mechanical energy and what factors affect its conservation?

Learning Objectives	Materials	Instructional Activities and Assessments
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 everyday systems. [LO 5.B.4.1, SP 6.4, SP 7.2] 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] 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]	**Web** "Bouncing Balls"	**Instructional Activity:** This brief simulation could be projected for whole-class viewing. In the simulation, a ball is launched from a certain height and it bounces according to the amount of energy lost during impact with the floor. The user can set the coefficient of restitution that determines what percentage of energy is lost.
	Student clickers or whiteboards	**Instructional Activity:** Students are shown diagrams illustrating various aspects of the work-energy theorem, and they must calculate the work done by components of the external force (e.g., the work done by the tension in the cable to lift an elevator 10 m at a constant velocity, the work done by the gravitational force as a crate is pushed 5 m across a floor, the work done by the normal force as a box slides 4 m down an inclined plane). I include examples that will result in answers being positive, negative, or zero. Students may respond with clickers or whiteboards.
	Teacher-produced quiz	**Formative Assessment:** Once students are comfortable with the calculations of the individual quantities of work, a quiz is given. In addition to calculations, I include several conceptual questions about positive versus negative work and work done when force and displacement are perpendicular to each other.
	Web "Conservation of Energy"	**Instructional Activity:** This Web-based investigation leads students through some basic questions of internal versus external forces, energy bar charts, friction as a means to reduce kinetic energy, and the energy transformations present on a roller coaster.

As students view this simulation, ask the purpose of the initial horizontal push, and ask whether this horizontal push affects the bounce height in any way.

I evaluate the quizzes, and misconceptions are identified and addressed in class through additional review and practice at the board.

Work and the Conservation of Energy

(continued)

Guiding Questions: ▼ How is the energy of a system defined? ▼ How is work represented graphically? ▼ What is mechanical energy and what factors affect its conservation?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	Atwood machine diagrams from previous unit, colored pencils	**Instructional Activity:** This is a continuation of an activity from the previous unit, where students drew an Atwood machine and calculated and marked the center of mass as the heavier mass descended to the floor. Students add to their diagram calculations and observations of the changes in the kinetic and/or potential energy of the center of mass.
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]	PASCO Dynamics Carts and Dynamics Tracks, friction blocks	**Instructional Activity:** The dynamics carts and tracks are used to demonstrate how friction does negative work on a sliding object and reduces its kinetic energy. With prompts from me, students discuss a way to use a block sliding down an incline to demonstrate the loss of energy due to friction. The dynamics carts are set atop friction blocks representing the object. The investigation begins with students calculating the velocity at the bottom of the incline (assuming a frictionless surface); then the experiment is conducted and the velocity at the bottom is determined in whichever way the students suggest, and the two velocities are compared.
	Web "5.5 Spring-Launched Bowler"	**Instructional Activity:** This ActivPhysics simulation has students consider the energy changes taking place for several different situations. In the first, a spring launches a person in a rocking chair toward a large glass of water. Students must calculate the force constant for the spring such that as the person slides across the floor, she will come to rest before smashing into the glass of water. This simulation effectively demonstrates to students how the frictional force does negative work and decreases the quantity of kinetic energy as the person slides to a stop. The coefficient of friction is provided as one of the variables.

Remind students that this activity reinforces the cumulative nature of physics principles and that they apply across many concepts and not just within one particular topic.

I emphasize the difference between calculated values for a velocity or acceleration compared to ones measured (determined) in a laboratory environment.

This visual could be formed into a word problem by having students consider the following situations: (1) calculate the coefficient of friction needed before the impact occurs; (2) using a given coefficient, determine what minimum distance is needed in order to stop in time; (3) what is the maximum initial kinetic energy to avoid the collision? These word problems could be the "bell ringer" for the next day, or used as a 5-minute postlab assessment.

Guiding Questions: ▼ How is the energy of a system defined? ▼ How is work represented graphically? ▼ What is mechanical energy and what factors affect its conservation?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] 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]	Student clickers	**Formative Assessment:** Students use clickers to respond to multiple-choice, concept-based questions as a review for the unit assessment. This could occur in a game format such as Jeopardy, learning pairs, or individual responses.
		Summative Assessment: Using available lab equipment, students design a lab demonstrating the conservation of mechanical energy. In the first portion of the designed lab, friction should not be a factor. In the second part, students should include energy losses due to friction. This activity could be curtailed and each lab group could be assigned an energy transformation to create (e.g., using the spring of the dynamics cart, designing a lab demonstrating the transformation from elastic potential energy to gravitational potential energy, or using a simple pendulum, designing a lab to demonstrate the gravitational potential to kinetic energy transformation). To differentiate assessment, some groups could be asked to include three or more energy transformations.

Students receive immediate feedback on their overall depth of understanding. By monitoring students' responses, I can assess the readiness of the students for a unit assessment. Depending on students' performance, an additional day of review might be provided or sample questions with solutions published to the website to specifically address areas of weakness.

All of the guiding questions in this unit are addressed in this assessment.

Unit 7:

Systems of Particles and Linear Momentum

Laboratory Investigations:

- Impulse and Momentum
- Bouncing Darts
- Conservation of Momentum in Collisions

Estimated Time: *3 weeks*

Guiding Questions: ▼ What role does Newton's third law play in the conceptual and mathematical understanding of impulse and momentum? ▼ How is the impulse and momentum demonstrated by air bags in cars, thick-soled running shoes, and knee bending during a landing? ▼ How are collisions determined to be elastic or inelastic? ▼ How does a ballistic pendulum demonstrate both the conservation of energy and momentum?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] 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]	Knight, Jones, and Field, Chapter 9: "Momentum"	**Instructional Activity:** To introduce this unit, I show the following demos: collide two dynamics carts such that upon colliding, the two carts join and stop; release two balls in a Newton's cradle; and toss a hard-boiled egg toward a student and have him or her catch it. Students brainstorm similarities and differences in these actions.
	Force-time graph	**Instructional Activity:** I project a force-time graph onto the board. While I bat a ball around volleyball style, kick it around soccer style, or shoot it basketball style, I ask students to think collaboratively and determine how the graph matches the actions.
	Web Golf ball compression video or "Slow Motion Rugby Ball Kick at 1000 Frames Per Second"	**Instructional Activity:** First, I show slow-motion footage of some kind of collision where shape deformation is obvious. Next, students discuss the actions that are occurring along the curve of the graph.
	Student clickers	**Formative Assessment:** Students use their clickers to answer conceptual questions based on several force-time graphs that are projected on the board. No calculators are allowed. Students may be asked to calculate an impulse based on the area under the curve, but the values would allow for calculations to be completed without a calculator.

When selecting force-time graphs: some will reflect a bell-shaped curve — it is difficult to determine the area under without calculus; others are more triangular and area can easily be calculated. Either graph is fine qualitatively, but select triangular graphs with all quantitative aspects.

As the quiz questions are answered, I can view a real-time chart that shows the responses for each student. Correct responses will be in green, incorrect in red. This provides me with immediate information on how many students missed a particular question and what the distribution of incorrect answers was. This data can guide discussion to address common incorrect responses if needed.

Guiding Questions: ▼ What role does Newton's third law play in the conceptual and mathematical understanding of impulse and momentum? ▼ How is the impulse and momentum demonstrated by air bags in cars, thick-soled running shoes, and knee bending during a landing? ▼ How are collisions determined to be elastic or inelastic? ▼ How does a ballistic pendulum demonstrate both the conservation of energy and momentum?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] 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] 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]	Student clickers, teacher-produced problem set: impulse and momentum	**Instructional Activity:** After I lead a discussion on impulse and change in momentum and the impulse-momentum theorem, students solve several word problems in class and submit answers via clickers. Then the students complete a set of practice problems. This begins in class and is completed as a homework assignment.
	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Cars—Impulse During a Change of Velocity"	**Instructional Activity:** This task has students rank six situations according to impulse delivered to a system, given only initial and final velocities and the mass of the object. I allow time for individuals to work on the task before group discussion begins.
	Appel et al., "Impulse and Momentum" Motion detector, force sensor, dynamics cart, laptops	**Instructional Activity:** This lab provides the opportunity for students to study collisions graphically and to gather data to determine the impulse acting on the cart.
	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Force Pushing Box—Final Momentum"	**Instructional Activity:** This ranking task shows six situations in which a given force is exerted on a certain mass object. Based on the force delivered to the mass, students rank each situation according to the final momentum. All boxes have the same initial velocity. Students must make a connection between direction of net force, acceleration, and momentum change.

I ensure that students have ample practice with momentum-change calculations involving a change in direction, or bounce. If the direction changes, the sign of the velocity also changes. The common error is to take the difference in the initial and final velocities without regard to the change in sign due to velocity direction change.

Guiding Questions: ▼ What role does Newton's third law play in the conceptual and mathematical understanding of impulse and momentum? ▼ How is the impulse and momentum demonstrated by air bags in cars, thick-soled running shoes, and knee bending during a landing? ▼ How are collisions determined to be elastic or inelastic? ▼ How does a ballistic pendulum demonstrate both the conservation of energy and momentum?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	Bouncing dart mallets	**Instructional Activity:** Each group is provided a bouncing dart mallet and posed the following question: *Which rubber tip delivers the greatest impact force — the rubber tip that bounces upon impact, or the rubber tip that does not bounce back?* Students may utilize any additional equipment or supplies as they design their lab. I visit with lab groups and listen for understanding of concepts to be applied. If one group is confused or unsure, I may send a volunteer from another group to explain things, or I may conduct a mini-lesson for those students.
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 2.2] 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] 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] 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]	**Web** "Practice: Momentum and Energy #1"	**Formative Assessment:** This online quiz utilizes a force-time graph and asks students for calculations regarding impulse and momentum change. The final section asks for calculations regarding a horizontally launched projectile.
	Knight, Jones, and Field, Chapter 9, end-of-chapter problems #4, 7, 8, 36, 37, 38, 39, 40, 41	**Formative Assessment:** I assign the end-of-chapter problems that are dependent upon correct interpretation of a force-time or velocity-time graph. Students work in small groups and check their answers against my answer key; I check them off as they answer each problem correctly.
	Teacher-produced quiz	**Formative Assessment** I create a quiz that covers impulse, change in momentum, and center of mass. Force-time graphs make up a large portion of this quiz.

Mallets are available from Arbor Scientific. The bouncing darts are T-shaped mallets with rubber hemispheres glued to the tips of the mallet. One rubber tip is made of a material that bounces and rebounds upon impact; the other tip is made of a rubber-type material that does not bounce. A second use of the bouncing darts is to have each dart tip strike the force sensor when released from the same initial height. This produces interesting force-time graphs.

I use information from the students' performance on the quiz to determine if additional whole-class instruction is needed, or if only certain individuals are in need of further review. Peer tutors may be assigned.

Other textbooks may also have end-of-chapter questions that could be utilized for this activity. I offer assistance to those student groups making mistakes.

If at least 80 percent of the students have mastered the objectives tested on the quiz, I proceed to new material and work individually with the students who need further review or help. If the success rate is lower, additional instruction and review is provided to the entire class, either in class or online.

Systems of Particles and Linear Momentum

(continued)

Guiding Questions: ▼ What role does Newton's third law play in the conceptual and mathematical understanding of impulse and momentum? ▼ How is the impulse and momentum demonstrated by air bags in cars, thick-soled running shoes, and knee bending during a landing? ▼ How are collisions determined to be elastic or inelastic? ▼ How does a ballistic pendulum demonstrate both the conservation of energy and momentum?

Learning Objectives	Materials	Instructional Activities and Assessments
	Dynamics carts	**Instructional Activity:** At this point, types of collisions are introduced. The lecture is interactive, with demonstrations of dynamics carts interposed to lend visual support. Students sketch the "before and after" scenarios and make predictions as to the momentum changes for each cart. The description of an elastic collision as one in which the kinetic energy is conserved is emphasized. Several mathematical examples are shown of both elastic and inelastic collisions.
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]	**Web** "Collision Lab"	**Instructional Activity:** To introduce two-mass systems and the idea of center of mass, I project the PhET interactive simulation and use it to illustrate the locations of the center of mass between two equally massed objects and between objects of varying masses. Then, I pose the question of how the center of mass position would change if one of the masses began to move toward or away from the other mass. On the "Advanced" tab of the simulation, both masses are in motion, and again the behavior of the center of mass can be seen.

I emphasize to students to be sure of signs for velocities. In a head-on collision, one object must have a negative velocity.

I prefer to project this for the whole class so that I may pause, pose questions, and assess understanding before changing the next variable.

Behavior of the center of mass receives a qualitative treatment since no calculations are specified in this course.

Systems of Particles and Linear Momentum

(continued)

Guiding Questions: ▼ What role does Newton's third law play in the conceptual and mathematical understanding of impulse and momentum? ▼ How is the impulse and momentum demonstrated by air bags in cars, thick-soled running shoes, and knee bending during a landing? ▼ How are collisions determined to be elastic or inelastic? ▼ How does a ballistic pendulum demonstrate both the conservation of energy and momentum?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] 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, SP5.1, SP 5.3] 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] 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] 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] ***(learning objectives continue)***	PASCO Scientific (for *Model ME-9435A and ME-9429A*), Experiment 2: "Conservation of Momentum in Collisions" (Part II) Dynamics carts and dynamics tracks, bar masses	**Instructional Activity:** In this lab, I allow ample time for qualitative observations before focusing on data collection and quantitative analysis. Students observe collisions of lab carts and predict the resulting relative velocities. Utilizing the probeware lab, students can generate real-time graphs of the velocities, thus momenta, before and after any collisions. When producing graphs, it is important to listen to students explain the significance of various points within the graphs.
	PASCO Scientific (for *Model ME-9435A and ME-9429A*), Experiment 2: "Conservation of Momentum in Collisions" (Part I) Dynamics carts and dynamics track **Web** "6.3 Momentum Conservation and Collisions"	**Instructional Activity:** With elastic collisions, the focus is typically on the conservation of kinetic energy. Again, I allow ample time for students to make qualitative observations before they analyze the quantitative aspects of the lab.
	Web Video clips from any source	**Formative Assessment:** In pairs, students locate a video clip (of less than 1 minute) that demonstrates some type of collision, and they share the video and a 1-minute explanation of the collision type and additional thoughts on momentum. There may be a peer-grading component, or a scoring rubric may be used by the teacher.

If you do not have PASCO equipment, Vernier software also has a really nice lab on momentum, collisions, and energy using their probeware.

If adequate dynamics carts are not available, the "Momentum Conservation and Collisions" simulation is a good option. This simulation also could be assigned for completion outside of class depending on time limitations, or it could be assigned to students prior to the lab being completed in class.

The class and I listen for content errors and mention those at the end of the presentation, and the presenting students have an opportunity to respond.

Guiding Questions: ▼ What role does Newton's third law play in the conceptual and mathematical understanding of impulse and momentum? ▼ How is the impulse and momentum demonstrated by air bags in cars, thick-soled running shoes, and knee bending during a landing? ▼ How are collisions determined to be elastic or inelastic? ▼ How does a ballistic pendulum demonstrate both the conservation of energy and momentum?

Learning Objectives	Materials	Instructional Activities and Assessments
(continued) 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. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and only qualitatively in two-dimensional situations. [LO 5.D.1.2, SP 2.2, SP 3.2, SP 5.1, SP 5.3]	Teacher-produced problem set: momentum and collisions	**Formative Assessment:** I create a problem set focusing on collision types and calculations of missing variables. The assessment of this assignment could be whole-class review, or students could independently check their answers against my answer key. In several of the problems, students must perform calculations based on the collision being inelastic and repeat calculations with the collision as elastic. I ask students to draw specific conclusions comparing the outcomes based solely on the type of collision.
	Dynamics carts	**Instructional Activity:** After mastery of one-dimensional collisions, the concept of *explosions* is introduced. This is an interactive lecture supplemented by the dynamics carts. Students sketch pre- and post-explosion diagrams. Video clips of real-world situations such as a cannon firing may also be used. One helpful website is The Physics of Everyday Stuff, which includes animations of ballistics being fired.
	Web "6.7 Explosion Problems"	**Instructional Activity:** In this simulation, a sphere is launched and explodes into two pieces at the highest point in its trajectory. The simulation displays the paths of the two pieces. Students predict the landing locations for the two pieces, utilizing impulse and conservation-of-momentum principles. The simulation does a good job of supplying questions for students to consider as they work through the simulation.
		Instructional Activity: Students design and build a device that demonstrates both Newton's third law and the conservation of momentum. Several days and a weekend are allowed before the final product is due. Students present their device to the whole class and demonstrate its operation.

I evaluate students' understanding in the whole-class discussion or as they check their answers against my key. This helps me determine whether any reteaching is required.

The device could be as simple as a balloon rocket or may be a more elaborate device.

Systems of Particles and Linear Momentum

(continued)

Guiding Questions: ▼ What role does Newton's third law play in the conceptual and mathematical understanding of impulse and momentum? ▼ How is the impulse and momentum demonstrated by air bags in cars, thick-soled running shoes, and knee bending during a landing? ▼ How are collisions determined to be elastic or inelastic? ▼ How does a ballistic pendulum demonstrate both the conservation of energy and momentum?

Learning Objectives	Materials	Instructional Activities and Assessments
	Web "6.5 Car Collision: Two Dimensions"	**Instructional Activity:** To treat collisions in two dimensions, the ActivPhysics simulation is projected onto the board. The simulation is paused at appropriate times to allow students to predict the outcome for the next section. The velocities for each car are shown prior to and after the collision. Students perform calculations and then run the simulation to check their responses. A second animation allows for a head-on collision between two objects whose mass proportion can be adjusted and/or to have a head-on collision slightly offset so that each object bounces off at an angle from the original path. This animation is purely qualitative in nature.
	Ballistic pendulum or video clip of ballistic pendulum	**Instructional Activity:** The final aspect of this unit is introduced with the ballistic pendulum, which combines the two conservation laws. This is an interactive lecture centered on the ballistic pendulum and its operation, as well as the physics behind its operation. Students sketch and make predictions throughout the lesson.
	Web "6.8 Skier and Cart"	**Instructional Activity:** In this simulation a skier slides along and collides with a cart attached to a spring. After the collision, the skier and cart compress the spring a certain distance. Students must use the conservation of momentum and energy to determine how far the spring is compressed. The simulation contains prompts as well as an "Advisor" tab to offer hints to students as the problem is worked.

The center of mass can be shown in this animation, which can be turned on to reiterate previous statements made about the action of the center of mass during a collision. For two-dimensional collisions, students are required to make only qualitative observations, not quantitative analyses. This is an opportunity for instructional differentiation whereby more advanced students could perform the calculation for collisions in two dimensions and others could stick with qualitative observations.

Guiding Questions: ▼ What role does Newton's third law play in the conceptual and mathematical understanding of impulse and momentum? ▼ How is the impulse and momentum demonstrated by air bags in cars, thick-soled running shoes, and knee bending during a landing? ▼ How are collisions determined to be elastic or inelastic? ▼ How does a ballistic pendulum demonstrate both the conservation of energy and momentum?

Learning Objectives	Materials	Instructional Activities and Assessments
	Teacher-produced problem set: ballistic pendulum-type problems	**Instructional Activity:** I create a practice-problem set focusing on those problems requiring the use of both conservation laws. Another typical problem of this type involves a block that slides down a ramp from a given height and collides with a stationary block poised at the edge of the table. The sliding block may stick to or bounce off of the stationary block; either way, the block on the edge slides off of the table and travels a certain horizontal distance to the floor below.
		Instructional Activity: On easel-sized pieces of paper are six different word problems involving ballistics-type problems. These are posted on the walls throughout the classroom. The solutions are posted on a yellow sheet behind the poster. Students work in groups to move from one poster to another every 7 minutes, checking their answers before rotating to the next poster.
	Web "6.10 Pendulum Person-Projectile Bowling"	**Formative Assessment:** In this simulation, a pendulum swings down and strikes a "person" standing on the edge of a cliff. Once struck, the person leaves the cliff's edge and is supposed to land in a cart that is positioned some distance from the base of the cliff. The students have to calculate the initial height of the pendulum in order to give the person sufficient horizontal velocity to reach the cart below.

A variation is to have one class make a set of questions for the other classes to solve.

I keep an informal list of groups that calculate correctly on the first try, second try, etc., and I assist those groups that require more than two tries.

Guiding Questions: ▼ What role does Newton's third law play in the conceptual and mathematical understanding of impulse and momentum? ▼ How is the impulse and momentum demonstrated by air bags in cars, thick-soled running shoes, and knee bending during a landing? ▼ How are collisions determined to be elastic or inelastic? ▼ How does a ballistic pendulum demonstrate both the conservation of energy and momentum?

Learning Objectives	Materials	Instructional Activities and Assessments
	Teacher-produced unit assessment	**Summative Assessment:** This assessment requires three days, as it also contains a lab component. Both conservation laws are tested. The lab component of this assessment is a rotation involving six or seven stations. At each station a lab setup mirrors the word problems that have been attempted previously. Force-time graphs are provided with follow-up questions and word problems. One essay-type question is given wherein students must respond to a question regarding how impulse momentum is apparent in real-life situations (e.g., air mattress for stunt person, padded dashboards in cars). Several word problems are included that involve calculations of missing variables, as well as calculation of kinetic energy, to determine the type of collision.

All of the guiding questions in this unit are addressed in this assessment.

Unit 8:

Simple Harmonic Motion

Laboratory Investigations:

- Simple Harmonic Oscillator
- Pendulum

Estimated Time:

2 weeks

Guiding Questions: ▼ What is a simple harmonic oscillator? ▼ What factors affect the period of oscillation for a mass oscillating on a spring and for a simple pendulum? ▼ How does the back-and-forth motion of a box on a spring mirror the motion of a pendulum?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	Knight, Jones, and Field, Chapter 14: "Oscillations"	**Instructional Activity:** I demonstrate four different actions: (1) mass oscillating horizontally on a spring, (2) mass oscillating vertically on a spring, (3) a pendulum swinging back and forth, and (4) an oscillating fan. Students discuss and list similarities in pursuit of developing a working definition of *oscillations*, *restoring force*, and *simple harmonic motion*.
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] 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]	PASCO Scientific (for *Model ME-9435A and ME-9429A*), Experiment 3: "Simple Harmonic Oscillator" Timers, springs, dynamics carts and dynamics tracks	**Instructional Activity:** In this lab students measure the experimental period of oscillation using timers and they compare this to the theoretical oscillation period, which is calculated using a force-displacement graph that students create with their collected data. To extend this lab, I ask students to predict and then design an experiment to demonstrate how the spring constant changes when two springs are connected. A series connection would be end to end, a parallel connection would be side by side.
		Instructional Activity: After completion of the preceding lab, students discuss and predict which factors affect the period of oscillation for the mass on the spring. Students should consider how their responses might change if the mass were oscillating vertically. What if the mass were not on a spring but on a pendulum? Students can then predict what factors are significant in the oscillation period of the pendulum.
	Knight et al., *Student Workbook*, 14.3: "Describing Simple Harmonic Motion"	**Instructional Activity:** This handout reinforces simple harmonic motion as a wave on a position-time graph. It leads students through a progression of steps addressing position, velocity, and acceleration at various times, and it concludes with conceptual questions regarding changes to the variables when other variables are changed.

You could also use a "drinking bird," metronome, or grandfather-clock pendulum if available. Be sure to have a model of the three oscillating systems on display for students to see throughout this unit.

I like the graphing component of this lab. Ensure that students can draw connections between this force-displacement graph and the ones discussed in Unit 6.

Guiding Questions: ▼ What is a simple harmonic oscillator? ▼ What factors affect the period of oscillation for a mass oscillating on a spring and for a simple pendulum? ▼ How does the back-and-forth motion of a box on a spring mirror the motion of a pendulum?

Learning Objectives	Materials	Instructional Activities and Assessments
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 5.1]	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Springs and Masses—Period of Oscillating Mass"	**Instructional Activity:** In this ranking task, students are shown six sketches of horizontal mass-spring systems, and the values for spring constant and displacement are given. Students rank the systems according to the period of vibration. After working individually for several minutes, then as table groups for several more, each table group shares their findings with the whole class.
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] 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]	Pendulum bobs, string, metersticks, timers	**Formative Assessment:** Student groups design a lab, and then they collect and analyze data to support the factors that affect the period of oscillation for a simple pendulum.
	Ceiling hooks, string, hooked masses, metersticks, stopwatches	**Instructional Activity:** At each lab table, one pendulum is hung from the ceiling. Students experimentally determine the period for their pendulum and compare it to the calculated period. Then, each group is assigned a different planet. Students calculate the period of vibration for the pendulum on that planet, as well as determine the length of the pendulum on Earth if it is to have the same period on Earth as on the assigned planet.
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 5.1] 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]	Student clickers	**Instructional Activity:** To extend the basic concepts of harmonic oscillators, these concepts are partnered with conservation of energy and cases involving equilibrium. These could be solved in a handout, an online self-quiz, or problems could be posted on the walls of the classroom for group viewing. I project several samples on the board for students to solve and respond to with clickers.

I visit each group and approve its progress or offer assistance if needed. For the struggling groups, I may provide verbal prompts to guide their approach to the problem or may swap a few group members in order to have a student in each group that has a solid grasp of the necessary procedures.

Simple Harmonic Motion

(continued)

Guiding Questions: ▼ What is a simple harmonic oscillator? ▼ What factors affect the period of oscillation for a mass oscillating on a spring and for a simple pendulum? ▼ How does the back-and-forth motion of a box on a spring mirror the motion of a pendulum?

Learning Objectives	Materials	Instructional Activities and Assessments
	Teacher-produced problem set: momentum, oscillations, and conservation of energy	**Formative Assessment:** I create a problem set focusing on multistep word problems such as the following: 1. Block *A* slides across a frictionless surface and collides with block *B* which is attached to a spring. After the collision, calculate the maximum compression of the spring as well as its period of vibration. 2. A ball of mass m_1 is held suspended by a string that makes an angle of 40° with the vertical. After calculating tension in the string, the string is cut, and the ball is free to swing; calculate its period.
	Teacher-produced unit assessment	**Summative Assessment:** Student experimental design has been thoroughly investigated in this unit. The unit assessment focuses on multipart free-response questions with both calculations and conceptual questions present. One problem will consist primarily of a pendulum, and another will focus on a mass oscillating on a spring.

A whole-class review of the solutions takes place on the following day. I provide direct feedback to student responses during the discussion. Based on the responses of the students and questions asked in class, I may assign a few additional problems for the class, or provide individual assistance to those students still having difficulties with the multistep problems.

All of the guiding questions in this unit are addressed in this assessment.

Unit 9:

Universal Gravitation and Orbits

Laboratory Investigations:

- Gravity Force Lab
- Satellites Orbit
- Gravity and Orbits

Estimated Time:

2 weeks

Guiding Questions: ▼ How is the motion of a falling apple similar to the orbit of the moon? ▼ Why does a person's weight vary at various locations throughout the universe? ▼ How are the two equations used to calculate gravitational force similar and/or different?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	Knight, Jones, and Field, Chapter 6: "Circular Motion, Orbits and Gravity" **Online video** "The Apple and the Moon"	**Instructional Activity:** This 30-minute video introduces Newton's law of universal gravitation and presents the gravitation equation. It also does a thorough job of explaining gravitational acceleration and demonstrating this principle through animation of Newton's cannon. It ties the falling-apple legend with the falling orbits of planetary bodies.
		Instructional Activity: As part of a classroom discussion, students use the universal-gravitation equation to determine the force of gravity that Earth exerts on them. They will see that this calculation yields the same results as the previously investigated calculation of weight (mass × gravity). This reinforces the idea that a person's weight is the same as the force of gravity.
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] 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 between two objects and use that force in contexts involving orbital motion. [LO 3.C.1.2, SP 2.2]	**Online video** "How to Weigh the Earth"	**Instructional Activity:** This 5-minute video reviews the universal-gravitation equation, Cavendish's torsion balance, and calculation of the gravitation constant. It concludes with an explanation of how the mass of the Earth can be determined in a science classroom.

When I show videos of this length to the whole class, in addition to displaying the guiding questions for the unit, I may add a few video-specific questions for them to consider. Or I might have students come up with five questions as they view the video, and those questions will be shared with the class at the end.

After the video, I lead a discussion about how the mass of the Earth is determined. This is one of those universal questions that pop up in physics.

Universal Gravitation and Orbits

(continued)

Guiding Questions: ▼ How is the motion of a falling apple similar to the orbit of the moon? ▼ Why does a person's weight vary at various locations throughout the universe? ▼ How are the two equations used to calculate gravitational force similar and/or different?

Learning Objectives	Materials	Instructional Activities and Assessments
	Student clickers **Web** "Gravity Force Lab"	**Instructional Activity:** As part of the discussion I lead on universal gravitation, special attention is paid to the gravitation equation. This PhET simulation is simple yet effective for demonstrating how Newton's third law plays a role in the gravitational force of attraction between any two masses. I project this to the whole class and have them use clickers to enter both conceptual answers via multiple choice and numerical values for calculations.
	Web "4.6 Satellites Orbit"	**Instructional Activity:** In this ActivPhysics simulation on orbits of satellites, students calculate necessary velocities to achieve a requested orbital radius.
	Web "Gravity and Orbits"	**Instructional Activity:** This simulation allows students to choose the sun, Earth, moon, or satellite and manipulate variables such as mass and radius, then view the resulting orbit. Vectors for gravitational force, tangential velocity, and path can be displayed. There is also an option to "turn off" gravity, where students can see the result of the loss of gravitational force and how the orbiting body continues to travel in a straight path tangent to the orbit.
	Web "DIY Podcast: Sports Demo Video Clips"	**Instructional Activity:** As a preview to the Planetary Olympics project, I show the NASA clips of astronauts playing different sports in space.

The prediction of an orbiting object's path once the centripetal force is removed is a frequently asked question. This simulation provides a nice visual of that concept for students.

Given sufficient time, I may add the Planetary Olympics as a special activity, including sideline reporters and possibly having students create mini-videos.

Guiding Questions: ▼ How is the motion of a falling apple similar to the orbit of the moon? ▼ Why does a person's weight vary at various locations throughout the universe? ▼ How are the two equations used to calculate gravitational force similar and/or different?

Learning Objectives	Materials	Instructional Activities and Assessments
		Instructional Activity: After I lead a discussion on gravitational field strength, I assign each group a planet (if there are more groups than planets, I select a few moons as well) and provide radius and mass data for each. The groups then determine the gravitational field strength for their assigned planet. Each group performs a few kinematic-type calculations for objects in free fall. I provide a common set of questions or design this activity around a Planetary Olympics event in which astronauts compete in pole vault, high jump, slalom skiing, shot put, gymnastics, basketball, etc.
	Teacher-produced problem set: universal gravitation Student clickers	**Instructional Activity:** I create a problem set addressing calculations using the gravitation equation as well as conceptual questions pertaining to the inverse square nature of the equation. Depending on class time, a few may be completed in class and responses entered via clickers to ensure that everyone is on the right track to complete the assignment individually at home.
	Student clickers **Web** "The Law of Universal Gravitation"	**Formative Assessment:** This handout poses several questions addressing the inverse square law. I project this and have students use clickers to respond as an opening activity. Following review of the homework assignment, students answer the same set or a similar set of questions, using clickers, again as a wrap-up to assess progress.
	Web "Gravitational Field Quiz"	**Formative Assessment:** Students complete a quiz on gravitational field. This activity may be undertaken in class using clickers or completed online at home.

The greatest struggle I had to overcome was the idea that gravitational field strength is equivalent to g*, the acceleration due to gravity. This idea seems strange to me in that an acceleration describes a strength. I explain to students that the gravitational field strength at a point is the gravitational force per unit mass, which will have units equal to those of acceleration.*

This quick assessment is done first thing in class, and I note how well the class responds. Then, the previous night's homework is reviewed and special attention is paid to those concepts or calculations that were missed at the beginning of class. When necessary, I provide direct feedback to students to correct misconceptions.

The goal is a score of 85 percent correct. Students taking more than two tries to achieve this level of success will be provided additional instruction and an additional set of problems.

Universal Gravitation and Orbits

(continued)

Guiding Questions: ▼ How is the motion of a falling apple similar to the orbit of the moon? ▼ Why does a person's weight vary at various locations throughout the universe? ▼ How are the two equations used to calculate gravitational force similar and/or different?

Learning Objectives	Materials	Instructional Activities and Assessments
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] Articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored. [LO 3.G.1.1, SP 7.1] Use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges (interactions between collections of electric point charges are not covered in Physics 1 and instead are restricted to Physics 2). [LO 3.C.2.1, SP 2.2]		**Instructional Activity:** As a means of reviewing this portion of the unit and forecasting future occurrences of an inverse square law, I orient students to Coulomb's equation. They collaboratively list similarities and differences between the two, and they calculate the gravitational force of attraction and electrical force of attraction between an electron and proton at a separation of 0.5 nm. It will become obvious that the electrical attraction is much stronger than the gravitational one. This is also an opportune time to restate the peculiar fact that gravity is the only force that is solely attractive with no repulsive component. Two protons are attracted gravitationally, yet repelled electrically.
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]		**Summative Assessment:** Students may choose to either design an experiment featuring microgravity to be conducted on the International Space Station, or design an experiment to measure the gravitational field strength on a chosen planet.

All of the guiding questions in this unit are addressed in this assessment.

Unit 10:

Rotational Motion

Laboratory Investigations:

- Angular Kinematics
- Calculating Torque
- Truss Lab
- Rotational Equilibrium
- Net Torque and Angular Acceleration
- Net Torque and Change in Angular Momentum

Estimated Time:

4 weeks

Guiding Questions: ▼ Can the kinematics equations be applied to rotating systems? ▼ How can Newton's law be applied to rotating systems? ▼ How does a net torque affect the angular momentum of a rotating system?

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]	Knight, Jones, and Field, Chapter 6, sections 6.1 and 6.2: "Uniform Circular Motion" and "Speed, Velocity, and Acceleration in Uniform Circular Motion" Arbor Scientific Rotational Inertia Demonstrator	**Instructional Activity:** To introduce rotational kinematics, an Arbor Scientific Rotational Inertia Demonstrator is attached to each lab table. Students apply a force and observe the masses as they rotate about the axis. They are guided to find similarities between the rotational motion they are observing and the linear kinematics from earlier in the year. Terms such as *rotational* or *angular displacement, velocity*, and *acceleration* are used. The equations for rotational kinematics are revealed through this activity and discussion.
Make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. [LO 4.A.2.1, SP 6.4]	**Web** "Rotational Kinematics"	**Instructional Activity:** This online lesson reinforces the ideas from the previous discussion on rotational kinematics, and it provides some concrete examples for students to practice and review.
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]	Rotational inertia devices, metersticks, stopwatches	**Instructional Activity:** Using the rotational inertia devices, students perform several calculations involving angular displacement and velocity, as well as angular acceleration as the device slows to a stop.
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]	Knight, Jones, and Field, page 195, problems 1–16.	**Instructional Activity:** A rotational-kinematics problem set is assigned for homework.
Make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. [LO 4.A.2.1, SP 6.4]	**Web** "Circular Motion"	**Instructional Activity:** As a way of teaching the concept of centripetal acceleration, I use this applet projected onto the board to demonstrate the vector nature of the centripetal acceleration and force. Variables may be changed with the resulting outcomes visualized.

In my experience, rotational kinematics needs to be understood before tackling the dynamics of rotational motion. Instructional activities for rotational kinematics should take approximately five to seven class days, depending on how much time is spent on inquiry with the rotational inertia devices.

This device looks like a windmill with four arms and each arm has a movable mass affixed to it and rotates on a very smooth axle. One great feature of this device is that the rotation axle has several diameters, which allow for varying torques. I have made a similar device with TinkerToys and also PVC pipe. The spinning motion is enough to pique the curiosity of students.

Guiding Questions: ▼ Can the kinematics equations be applied to rotating systems? ▼ How can Newton's law be applied to rotating systems? ▼ How does a net torque affect the angular momentum of a rotating system?

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 6.4, SP 7.2]	Varieties of force gauges and probes, metersticks, string, spring scales	**Instructional Activity:** This inquiry-based activity follows a presentation of centripetal force and practice with the mathematics involved. Students may use any kind of force gauge to determine the radius of a circle.
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]	Knight et al., *Student Workbook*, pages 6-1 and 6-2	**Instructional Activity:** As students work through these two pages, I circulate among them, verifying and guiding their responses. At the conclusion, correct responses are shared and any misconceptions are clarified.
Design an experimental investigation of the motion of an object. [LO 3.A.1.2, SP 4.2]	Rotational inertia devices, hooked masses, string, timers, metersticks	**Formative Assessment:** Using the rotational inertia devices, students design a lab demonstrating at least two of the kinematics concepts from the perspective of both translational or linear kinematics and rotational kinematics. Students submit a lab procedure to be shared with the whole class. Allow two days for this (once the lab procedures are complete). On the third day, I choose two of the submitted lab procedures and create a mini-lab in which two experiments are set up and the class has 25 minutes for each procedure.
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]	Student clickers, suction-cup hooks, spring scale, broom, pry bar, can of paint	**Instructional Activity:** Through an interactive lecture, the concept of torque is developed. Students use clickers as I demonstrate various actions involving torques and pose questions. I attach three or four suction-cup hooks in a horizontal line from hinge to handle on the classroom door, and then I exert a force to open the door with a spring scale. Students read and record the force values as well as the lever-arm length. The classroom door is a great device to demo torque, as is a broom or pry bar, since they pivot at the handle. The equation for the calculation of torque should be developed during this lesson.

At my school there is a large rotunda near the main entrance that we use for this activity. I also thought about going to our track and using the circle where the discus and shot put are launched. Students are free to use any type of equipment available. Some choose to use probes, but some go low-tech and use the spring scales.

Feedback occurs as I visit each lab group and assesses their progress. I can also tell if a group is struggling by the quantity and types of questions they ask.

Guiding Questions: ▼ Can the kinematics equations be applied to rotating systems? ▼ How can Newton's law be applied to rotating systems? ▼ How does a net torque affect the angular momentum of a rotating system?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	Rotational inertia devices, string, hooked masses	**Instructional Activity:** Using the rotational inertia devices with the arms removed, students design an experiment to determine which radius of the rotating axle provides the greatest torque and to calculate the torque for each.
Estimate the torque on an object caused by various forces in comparison to other situations. [LO 3.F.1.3, SP 2.3]	Knight et al., *Student Workbook*, 7.2: "Torque"	**Instructional Activity:** Following the idea of torque as force multiplied by the length of the lever arm, the concept of components of force and lever arm being perpendicular are developed and practiced. The student workbook has a nice lesson to support this concept.
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]	Truss apparatus, spring scales, metersticks, hooked masses	**Formative Assessment:** In this lab, a truss apparatus is used, which allows one end of a beam to be fixed in a rotating hinge. Student groups use spring scales and apply perpendicular forces at several points on the beam and calculate torques; this is followed by an investigation with the force being applied at various angles to the free end of the rod. Each different trial is sketched and calculations are recorded. To conclude, each group explains their results in 1–2 minute presentations. A truss apparatus can also be made using a sturdy meterstick that has a hole drilled in one end. Secure the meterstick by using a nail through that hole into a sturdy block that is clamped to the table.
	Metersticks, support stand, hooked masses, knife edge clamps	**Instructional Activity:** In this activity, students are provided a meterstick, a support stand in which the meterstick may balance, and several knife edge clamps. First, the students balance the meterstick at its center of mass; then they design the remainder of the experiment to incorporate the use of three, then four, additional masses to maintain a balanced system. The goal is not to rely on trial and error; encourage students to consider the conditions necessary for the torques to balance.

This relatively simple activity will be extended later in this unit.

I visit each lab group and have the members demonstrate a few of their trials and share their observations and calculations. I assess their understanding by their comments, and I provide feedback to them and offer suggestions or hints to group members who are still uncertain about some of the concepts.

Guiding Questions: ▼ Can the kinematics equations be applied to rotating systems? ▼ How can Newton's law be applied to rotating systems? ▼ How does a net torque affect the angular momentum of a rotating system?

Learning Objectives	Materials	Instructional Activities and Assessments
	Web "7.1 Calculating Torques"	**Instructional Activity:** In this ActivPhysics simulation, students calculate the torque acting on a beam. This could be assigned for homework as a preinstruction activity or could be completed in class.
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]	**Web** "7.3 Arm Levers"	**Instructional Activity:** An interesting application of torque in a two-dimensional system occurs when you hold a heavy object at rest in your hand. The forces exerted by your arm muscles provide a torque that keeps the book at rest. Students discuss and discover the connections between physics and human anatomy with this ActivPhysics simulation.
	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Hanging Weights and Fixed Disks—Torque"	**Formative Assessment:** In this ranking task, students are shown six situations of various-sized rotating disks with objects of varying mass being released to produce a torque on the disk. Students rank the situations according to magnitude of the torque acting on the center of mass. Students work individually for the first 5 minutes, then discuss at their tables, and eventually each table presents their findings to the class and several minutes of whole-class discussion takes place to arrive at the correct ranking.
	Rotational inertia device, student clickers	**Instructional Activity:** In this interactive lecture, I guide students toward the concept of angular acceleration when a net torque acts on a rotating system. The rotational inertia device is again used as a visual aid. Students use clickers to answer questions regarding the calculation of the net force and of the angular acceleration. Students discuss the activity and then respond to questions about how the magnitude of the angular acceleration could be changed.

I listen and guide students along the best path toward understanding. An additional similar ranking task is available if anyone is still unclear.

I have included a link in the supplemental resources section that has nice visuals and accompanying concepts and calculations for this discussion. In addition, most textbooks have several end-of-chapter questions pertaining to this topic.

Guiding Questions: ▼ Can the kinematics equations be applied to rotating systems? ▼ How can Newton's law be applied to rotating systems? ▼ How does a net torque affect the angular momentum of a rotating system?

Learning Objectives	Materials	Instructional Activities and Assessments
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, 4.2, SP 5.1] 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]		**Instructional Activity:** The linear version of Newton's second law is written on the board alongside the rotational version of the same. Students discuss and develop an understanding of torque equaling the product of rotational inertia and angular acceleration. Each term in the rotational equation needs to be discussed.
	Rotational inertia devices, stopwatches, meterstick, hooked masses, string	**Formative Assessment:** Students design an experiment to demonstrate the relationship between net torque and angular acceleration. The rotational inertia devices are used. The design component describes a method to measure the rotational inertia, and the students will compare their measured results with calculated accelerations. Feedback occurs when these two values are compared. If the values agree within 10 percent, the experiment is a success. If not, the students may seek assistance from me for a second attempt.
	Student clickers, broom, baseball bat, Arbor Scientific Rotational Inertia Demonstrator	**Instructional Activity:** During this interactive lecture, students are introduced to the concepts and mathematics of rotational inertia. Analogies are drawn between inertia and rotational inertia. Using clickers, students answer conceptual questions such as the following: *Which has more rotational inertia, a hollow sphere or an equal-sized solid sphere? Which end of a broom is easier to balance in your palm and why?* I reiterate that rotational inertia is all about distribution of mass and provide students with the equations for rotational inertias for a variety of objects. Students then make calculations and use clickers to respond.

At this point, we are still dealing with the idea of angular acceleration being directly proportional to the net torque. We have not introduced the concept or calculations of rotational inertia.

If a large number of students struggle to begin this task, I may provide a few more hints at the board, or I may visit each group to assess progress. Success with this activity is necessary before the class moves on. I may need to spend additional class time on a few more paper-and-pencil examples before the students are ready for the independent investigation.

In using the Arbor Scientific devices, the value for the rotational inertia of the central axle is provided by the vendor. Guide students to somehow remove the torque at some point and determine the angular acceleration as the system comes to rest. This is done by using a short string on the falling mass, which will "run out" before the hanging mass strikes the ground, or the string could be cut as it descends.

Guiding Questions: ▼ Can the kinematics equations be applied to rotating systems? ▼ How can Newton's law be applied to rotating systems? ▼ How does a net torque affect the angular momentum of a rotating system?

Learning Objectives	Materials	Instructional Activities and Assessments
Use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum 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] 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] 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, SP5.1, SP5.3] 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] 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] 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] 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] ***(learning objectives continue)***	Knight, Jones, and Field, Chapter 9.7: "Angular Momentum" Knight et al., *Student Workbook*, 9.7: "Angular Momentum"	**Instructional Activity:** Students are encouraged to continue forming analogies between linear quantities and rotational ones. This activity focuses on angular momentum. Students brainstorm for 3 minutes and then share their thoughts on what angular momentum is and how it is similar to linear momentum. The accompanying handout from the student workbook will reinforce this discussion, or it could be assigned as a preinstruction activity to spark discussion during class.
	Online video "Circus Physics: Conservation of Angular Momentum"	**Instructional Activity:** After viewing this 2-minute video about angular momentum applied to circus performers, students brainstorm about other instances in the real world where knowledge or application of angular momentum can be seen. Next, students discuss and develop the concept of a net torque causing a change in angular momentum. This discussion should also lead to the development of the idea that net torque multiplied by time equals the change in momentum (or rotational inertia multiplied by the change in angular velocity).
	Rotational inertia devices, string, hooked masses	**Instructional Activity:** The activity with the rotational inertia devices could be repeated from an angular momentum perspective. Working in pairs or small groups, students design a lab using the rotational inertia devices to demonstrate how the net torque creates a change in angular momentum.
	Knight et al., *Student Workbook*, 7.2: "Torque"	**Instructional Activity:** Using the handout from the student workbook that was previously used to calculate components of forces and net torque, students discuss and share the resulting changes in momentum as caused by the net torques. Emphasize the use of the terms *clockwise* and *counterclockwise* to describe the direction of rotation.

The equation $L = I\omega$ *will be introduced here. Spend time discussing the concept of angular momentum before jumping to the conservation laws.*

In most of the popular word problems involving conservation of angular momentum, there is no net force acting on the system, so the angular momentum does not change.

Guiding Questions: ▼ Can the kinematics equations be applied to rotating systems? ▼ How can Newton's law be applied to rotating systems? ▼ How does a net torque affect the angular momentum of a rotating system?

Learning Objectives	Materials	Instructional Activities and Assessments
(continued) 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] 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] 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] 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. Students are expected to do qualitative reasoning with compound objects. Students are expected to do calculations with a fixed set of extended objects and point masses. [LO 5.E.2.1, SP 2.2]	Easel pad, markers	**Formative Assessment:** Working in pairs, students construct a poster depicting a real-world rotating system and then describe the changes to it as a result of a net torque. The poster should include pictures and/or sketches to show the rotating system, as well as supporting statements emphasizing the physical concepts. There are several reality-TV shows with great examples of giant rotating systems (*Wipeout*), several sports examples (baseball striking a bat), and others (Tarzan runs and grabs the rope swing, martial arts, dance moves, high diving, skydiving). Each pair presents to the whole class. Students are given several days to brainstorm and calculate their rotating system of choice. One day of class is allowed to produce the poster.
	Spinning turntable	**Instructional Activity:** In the absence of a net torque, the angular momentum of the system remains constant. The classic demonstration here is the spinning figure skater. Students are encouraged to ride the turntable in the classroom. After riding, a discussion takes place regarding slow velocity with arms stretched out and higher velocity when arms are brought in. Students then summarize that action by using appropriate physics terms and concepts.
		Instructional Activity: Rotational collisions typically involve a rod of some sort being impacted by some sort of sticky "blob." I project several problems of this type onto the board and have students discuss qualitatively how the momentum of the system will change; then they perform calculations for the angular velocity.

I visit each group and assess progress and understanding, and I provide additional instruction to struggling groups.

This type of problem also can be demonstrated in the form of a person sitting on a merry-go-round and changing her position relative to the axis of rotation and calculation of the resulting change in angular velocity.

Guiding Questions: ▼ Can the kinematics equations be applied to rotating systems? ▼ How can Newton's law be applied to rotating systems? ▼ How does a net torque affect the angular momentum of a rotating system?

Learning Objectives	Materials	Instructional Activities and Assessments
	Web "7.14 Ball Hits Bat"	**Instructional Activity:** In this simulation, a baseball strikes a rotating bat, changing its angular momentum. Sliders allow the student to change several variables and to view the resulting actions. Questions are posed for students to consider as they work through the simulation.
	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Rotating Systems of Point Masses—Difficult to Rotate"	**Instructional Activity:** In this ranking task, six arrangements of point masses are shown with varying positions of the rotation axis. Students evaluate the situations and rank them according to the difficulty or ease with which each system could be rotated.
	Teacher-produced unit assessment	**Summative Assessment:** I create a test assessing students' understanding of rotational kinematics and application of the rotational form of Newton's second law to solve for torque and then to extend the concept of torque into its influence on angular acceleration and momentum.

I keep a large container of TinkerToys handy for students who need to manipulate a model. TinkerToys are easy to assemble to fit most system descriptions.

All of the guiding questions in this unit are addressed in this assessment.

Unit 11: Mechanical Waves and Sound

Laboratory Investigations:

- Sound Waves and Beats
- Wave Speed, Wavelength, and Frequency
- Superposition of Waves
- Standing Waves
- Speed of Sound

Estimated Time:

3 weeks

Guiding Questions: ▼ How are velocity, frequency, and wavelength used to describe a wave? ▼ What factors affect how a wave is reflected? ▼ How is it possible for two waves to occupy the same space at the same time? ▼ What conditions are necessary to form a standing wave?

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] 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]	Knight, Jones, and Field, Chapter 15: "Traveling Waves and Sound" **Web** "Longitudinal and Transverse Wave Motion"	**Instructional Activity:** To begin the discussion of transverse and longitudinal waves, project the Web page onto the board. Motion of the source is clearly shown, as are the particles within the medium. Students describe how the two waves differ. Once a working definition is developed, students brainstorm examples of each type of mechanical wave using real-world examples.
Use graphical representation of a periodic mechanical wave to determine the amplitude of the wave. [LO 6.A.3.1, SP 1.4]	**Web** "10.1 Properties of Mechanical Waves"	**Instructional Activity:** In this simulation, properties of mechanical waves are animated, as is the difference between a wave pulse and a traveling wave. The animations are nice, and the guiding questions lay a concise baseline of knowledge for the students prior to any extensive study or discussion. Typically, for an ActivPhysics lesson that is completed outside of class, I have students create a two-column chart; the left side details what the student did for each section, and the right side describes what occurred as a result of the student's initial manipulation. These may be turned in, discussed in groups, or shared in class on the following day.
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]	Oscilloscope, tuning forks	**Instructional Activity:** I use several tuning forks and an oscilloscope to demonstrate the amplitude of the sound waves. With the oscilloscope, I explain that the transverse wave the students are viewing has been created by the oscilloscope as a representation of the sound wave. Student volunteers take turns striking various tuning forks, and the whole class views the displayed wave form. We discuss wavelength, frequency, and amplitude. I also lead them to make some qualitative observations about human ear sensitivity. The higher frequencies may not seem as loud to us because our ears are less sensitive, but viewing the wave on the oscilloscope, students can quantitatively compare the amplitudes.

Real-world examples include a stadium wave, bullwhip cracking, strings on an instrument, water waves, and waves in a wheat field ("amber waves of grain").

If an oscilloscope is not available, there are similar programs on the Internet or apps for smartphones that would work well.

Guiding Questions: ▼ How are velocity, frequency, and wavelength used to describe a wave? ▼ What factors affect how a wave is reflected? ▼ How is it possible for two waves to occupy the same space at the same time? ▼ What conditions are necessary to form a standing wave?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	**Web** "Waveform and Vibration Graphs #1"	**Instructional Activity:** This handout features wave graphs and accompanying questions pertaining to the graphs. Students complete the handout in small groups. Notice that one graph has time on the *x*-axis while the other has length on the *x*-axis. Associate the *x*-axis values with what can be interpreted from the graph: time on *x*-axis can give period and frequency; length on the *x*-axis can give wavelength. After students complete the worksheet, I use the wave graphs to guide additional discussion about how changes in certain variables would change certain wave properties.
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]	Appel et al., "Sound Waves and Beats" Tuning forks, Vernier probes	**Instructional Activity:** In this lab students use a tuning fork and computer interface to create wave graphs for several tuning forks. They use these graphs to identify frequency, wavelength, and period.
Describe representations of transverse and longitudinal waves. [LO 6.A.1.2, SP 1.2] Use a visual representation of a periodic mechanical wave to determine wavelength of the wave. [LO 6.B.2.1, SP 1.4]	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Wave Forms with Same Frequency—Wave Speed"	**Instructional Activity:** In this ranking task, students are shown six seismic wave graphs they must rank according to wave speed. All have the same frequency but varying amplitudes and wavelength.
	Web "Wave on a String"	**Instructional Activity:** Students work in pairs to explore the PhET simulation, using the online timer and ruler to make observations regarding wavelength, wave speed, and frequency.
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]		**Summative Assessment:** Students design an experiment to demonstrate the relationship between wave speed, wavelength, and frequency, including aspects of both interference and standing waves. A 2-minute video of the experiment in action is required. Students present their experiment video to the whole class.

If you do not have the Vernier probes, there is a really nice "Beats" ActivPhysics activity that includes sound files.

Prior to this activity, I will have demonstrated waves on a string for students using a rope.

All of the guiding questions in this unit are addressed in this assessment.

Guiding Questions: ▼ How are velocity, frequency, and wavelength used to describe a wave? ▼ What factors affect how a wave is reflected? ▼ How is it possible for two waves to occupy the same space at the same time? ▼ What conditions are necessary to form a standing wave?

Learning Objectives	Materials	Instructional Activities and Assessments
	Web "Applet: Doppler Effect"	**Instructional Activity:** During this interactive lecture, the Doppler effect is introduced. Students discuss Doppler radar from the weather channel and Doppler guns that policemen use to catch speeders. The Doppler effect applet is projected onto the board. The source that is producing the sound wave can be set into motion by dragging the mouse. Prior to setting the source into motion, students predict and sketch what the wave pattern will look like once the source begins to move. I help students draw a connection between the sketch of the wave pattern and what the wave observer would actually perceive.
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]	**Web** "Ripple Tank"	**Instructional Activity:** Once students are comfortable with the wave-front diagram, I project the virtual ripple tank onto the board. This simulation allows for more than one source and reflection from the boundary walls. Several wave properties and behaviors can be studied, such as frequency and its effect on wavelength. Circular wave fronts may be produced as well as planar waves.
	Knight, Jones, and Field, Chapter 16: "Superposition and Standing Waves" **Web** "Superposition Principle of Wave"	**Instructional Activity:** In this interactive lecture, the idea of superposition of waves is developed. The superposition applet is projected onto the board. Before the applet is played, students predict the wave shape that results when two waves of the same frequency overlap.

Guiding Questions: ▼ How are velocity, frequency, and wavelength used to describe a wave? ▼ What factors affect how a wave is reflected? ▼ How is it possible for two waves to occupy the same space at the same time? ▼ What conditions are necessary to form a standing wave?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	Knight et al., *Student Workbook*, 16.1: "Superposition and Standing Waves"	**Formative Assessment:** This handout presents initial diagrams of two wave pulses moving toward each other. The pulses vary in shape and orientation. Students have to consider the concepts of superposition and interference; then predict and sketch the resulting wave as the two overlap each other.
	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Pairs of Transverse Waves—Superposition" Student clickers	**Formative Assessment:** This ranking task, conducted in lab-table groups, focuses on transverse waves superimposing with a special emphasis on the amplitude and wavelength. To evaluate the superimposed wave form, students make a scale drawing before making their judgment. Ranks will be entered with the student clickers.
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] 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]		**Instructional Activity:** Students design an experiment to illustrate the superposition of waves; quantitative analysis is expected as well. Students will include in this experiment a plan to measure the amplitudes of the individual waves. A bonus component of this experiment could be to videotape the waves so that they could be played back in slow motion to allow for more quantitative analysis.
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] 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]	Snakey	**Instructional Activity:** Two student volunteers use a long snakey to produce a giant standing wave in class. Other students are asked to discuss features of the wave, as well as how the students must move to create the wave.

I walk among the students observing the sketches and listening to students' comments and questions as they work. I assist with guiding prompts when needed or may offer corrective suggestions to those students who are making incorrect sketches. Depending on the success of the students, I may or may not provide additional practice opportunities.

Student groups share their rank results with the whole class and time is allowed for groups to justify their responses. I listen and guide, if needed, the students to an agreed upon response. If one of the groups initially responds correctly, I ask that group to take the lead on explaining their reasoning to the whole class.

As students create traveling waves in a rope by wiggling the rope on the floor, they will discover that the floor is a great tool for measurements because of the 12-inch tiles used in our school.

Snakeys are the catalog names for long wire coils. These are sold by the same science suppliers that sell the Slinky-type giant springs. I also have a spool of elastic cord that I picked up from an upholstery store that can sometimes be used to create waves.

Guiding Questions: ▼ How are velocity, frequency, and wavelength used to describe a wave? ▼ What factors affect how a wave is reflected? ▼ How is it possible for two waves to occupy the same space at the same time? ▼ What conditions are necessary to form a standing wave?

Learning Objectives	Materials	Instructional Activities and Assessments
	String vibrators, slotted masses, metersticks, stroboscope	**Instructional Activity:** As a way of introducing standing waves, students perform this lab. Initially, I demonstrate the vibrating apparatus and create a standing wave, and I use that wave to teach from. Students continue with the lab and use a vibrating source to create a standing wave. Students may vary the tension in the string but not its frequency, since the source vibrates at 60 Hz. By varying the tension in the string, several modes of vibration are seen in the produced standing wave. Students must create at least four different standing-wave modes. By measuring wavelength and using tension to calculate wave speed, the goal of calculating frequency of vibration can be accomplished.
Analyze data or observations or evaluate evidence of the interaction of two or more traveling waves in one or two dimensions (i.e., circular wave fronts) to evaluate the variations in resultant amplitudes. [LO 6.D.2.1, SP 5.1]	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Standing Waves—Frequency"	**Formative Assessment:** In this ranking task, six sketches of standing waves are shown along with their amplitude and string length. Students rank the six situations according to frequency. As with most ranking-task activities, students work for 5 or so minutes alone, then share with their group members for several more minutes, and finally a whole-class discussion takes place.
	Appel et al., "Speed of Sound" Vernier microphone and speaker, meterstick	**Instructional Activity:** In this lab, a microphone and computer interface will be used to produce a pressure wave representing the sound wave generated in a closed tube. From the gathered data, students calculate the speed of sound. This lab can be extended to include an open tube.

I made the string vibrator out of an air pump for an aquarium. This was much less expensive than the ones available through science suppliers. I also provide the equation for wave velocity dependent on string tension and mass density. At the conclusion of this lab, I use the stroboscope to "freeze frame" the wave — this is one of those memorable moments in physics.

I visit each group and listen to their conversations to assess progress. I may assist if the group is stuck, or I may reassign a group member to help with peer tutoring.

This lab using glass tubes and graduated cylinders is described on many websites. The students are excited the first time they hear a resonant sound wave.

Guiding Questions: ▼ How are velocity, frequency, and wavelength used to describe a wave? ▼ What factors affect how a wave is reflected? ▼ How is it possible for two waves to occupy the same space at the same time? ▼ What conditions are necessary to form a standing wave?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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]		**Instructional Activity:** After a lesson on the specifics of standing waves on strings and in columns of air, including the mathematics for frequency and wavelength, and vibrating modes for strings and air columns, students design an experiment, plan the data-collection method, and predict an outcome for their experiment. Half of the class is assigned a stringed instrument while the other half will use an instrument that relies on a vibrating column of air. Variables to be tested might include string density, tension in string, or air temperature. A required component of this activity is a poster diagramming at least the first four vibrating modes for the assigned instrument.
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]	**Web** "Standing Wave (Explanation by Superposition with the Reflected Wave)"	**Instructional Activity:** As a way of wrapping up the lessons on standing waves, I project the applet onto the board and use the pause button and step features to carefully explain all of the component parts of the standing wave. Several questions are posed to the class regarding the physics behind a standing wave, and students must design a plan for an experiment to highlight the particular question that is assigned to their group. Questions might include: *How are nodes and antinodes formed? What type of "ends" are needed to produce a reflected wave to establish a standing wave? What kind of reflected wave is needed to create a standing wave? Does frequency play a role in the formation of a standing wave?*
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]	Knight et al., *Student Workbook*, 16.3: "Standing Waves on a String"	**Formative Assessment:** Students work in small groups on this exercise. The activity requires them to sketch standing waves with the application of the frequency and wavelength equations. These will be collected so that I may carefully assess the students' understanding of the mathematics involved with the standing waves.

Having students include standing-wave sketches as often as possible reinforces their conceptual understanding and leads to better understanding of the sometimes confusing math.

For this activity, I allow my student musicians to use their own instruments as their model. Those with no preference will be assigned an instrument type.

During class the next day, each group shares with the class the results of their investigation.

I note incorrect responses on the papers, but I do not assign a grade. The following day, I address the concepts and calculations that were missed.

Mechanical Waves and Sound

(continued)

Guiding Questions: ▼ How are velocity, frequency, and wavelength used to describe a wave? ▼ What factors affect how a wave is reflected? ▼ How is it possible for two waves to occupy the same space at the same time? ▼ What conditions are necessary to form a standing wave?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	**Web** "Beat Frequencies in Sound"	**Instructional Activity:** I demonstrate beats using large resonance forks. Having heard no explanation, students are asked to discuss and pose a possible explanation for what they are hearing. Following this demo, I play the audio clip of beats and pose the following question: *How can knowledge of beats be helpful when tuning an instrument?*
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] 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]	Teacher-produced unit assessment	**Summative Assessment:** I prepare a unit test containing both multiple-choice and free-response questions. The test contains wave diagrams that require students to determine the wavelength, frequency, and speed. Students must sketch diagrams of waves interfering and standing waves, along with their characteristics.

All of the guiding questions in this unit are addressed in this assessment.

Unit 12: Electric Charge, Current, and Resistance

Laboratory Investigations:

- Charges in a Penny
- The Electroscope Inquiry
- Circuits and Conservation Laws

Estimated Time:

3 weeks

Guiding Questions: ▼ What is the cause of static electricity? ▼ How are electric forces similar to gravitational forces? ▼ How does an electric circuit demonstrate conservation of charge? ▼ What factors affect the resistance of a wire?

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] 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]	Knight, Jones, and Field, Chapter 20: "Electric Fields and Forces"	**Instructional Activity:** Students are shown several instances of common items becoming charged and must explain the behaviors they observe. This proceeds into a teacher demonstration with electroscopes or suspended uncharged rods and how they interact in the presence of other charged objects. I allow time for students to predict changes that are likely to occur. The goal is for students to develop operational definitions of *static electricity*, *charge*, and *conservation of charge*.
		Instructional Activity: To reinforce the idea of electrons as charge carriers, and to further explain the concept of charge, students determine the number of electrons in one solid copper penny. This could be performed in lab groups or as whole class.
	Knight et al., *Student Workbook*, 20.1: "Charges and Forces" and 20.2: "Charges, Atoms, and Molecules"	**Instructional Activity:** These two activities guide students through several thought experiments in which they predict behaviors of neutral and charged objects as those objects interact with other charged objects.
	Electroscopes, balloons, glass rods, fur pieces, silk pieces	**Instructional Activity:** In this investigational activity, students are given minimum instruction and must design activities to answer a set of posed questions pertaining to electric charge such as the following: *How can an object become charged? How can one determine which type of charge is present? How can charge be removed from an object?* Each lab group has an electroscope, plastic rod, fur piece, glass rod, silk piece, and inflated rubber balloon. If groups have difficulty providing predictions, I supply a few prompts.

This is a nice review of mole conversions and other prior knowledge from a chemistry course. The goal is to give an idea of how many charges can be present in very small objects and to reinforce that "a charged object" means a quantity of net charge, not total number of charges.

Guiding Questions: ▼ What is the cause of static electricity? ▼ How are electric forces similar to gravitational forces? ▼ How does an electric circuit demonstrate conservation of charge? ▼ What factors affect the resistance of a wire?

Learning Objectives	Materials	Instructional Activities and Assessments
		Formative Assessment: Working in small groups, students develop and share their working definition of *conservation of charge* and describe how it is analogous to one other conservation law, providing evidence or observations to support their claim. Each table shares its response with the whole class.
	Web "How Shocking"	**Instructional Activity:** In this short simulation, students see demonstrations of all three of Ben Franklin's experiments: static electricity, kite in a storm, and lightning rod. Students select various materials to use in the online simulation. Knowledge of charging materials and insulators versus conductors is applied.
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] 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] Use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges (interactions between collections of electric point charges are not covered in Physics 1 and instead are restricted to Physics 2). [LO 3.C.2.1, SP 2.2]	**Web** "Millikan's Oil Drop Experiment"	**Instructional Activity:** In this simulation, students assume the role of Robert Millikan. They view many tiny droplets inside the chamber and adjust the magnitude of the electric field in order to manipulate the acceleration of the isolated charge, in much the same way that Millikan did.
		Instructional Activity As a continuation of the preceding activity, students use the Millikan simulation and devise a model to explain the motion of the droplets and/or devise a procedure to measure the charge on a droplet.
	Student clickers	**Instructional Activity:** In this interactive lecture, students are introduced to Coulomb's law of electrostatic attraction and repulsion. As the equation is presented, students use the clickers to register their responses to questions regarding the inverse square nature of the law and to perform calculations. At this time, I revisit the idea (first put forth during the gravitation unit) that has students compare the gravitational force of attraction between two subatomic particles to the electrostatic attraction or repulsion between the same two particles.

I listen to their responses and add to the discussion if there are information gaps or misunderstandings.

With the Millikan experiment you have a great opportunity to review the concept of fields exerting forces as well as Newton's first law wherein balanced forces result in no net force.

As the lecture progresses, I pause and have students respond to a few conceptual questions and/or calculations.

Electric Charge, Current, and Resistance

(continued)

Guiding Questions: ▼ What is the cause of static electricity? ▼ How are electric forces similar to gravitational forces? ▼ How does an electric circuit demonstrate conservation of charge? ▼ What factors affect the resistance of a wire?

Learning Objectives	Materials	Instructional Activities and Assessments
		Formative Assessment: Students are assigned two subatomic particles and they must calculate the electrostatic force of attraction/repulsion between them and the gravitational attraction between them. Then they determine how large the masses of the two would need to be in order for the gravitational force to equal the electrostatic force.
Choose and justify the selection of data needed to determine resistivity for a given material. [LO 1.E.2.1, SP 4.1]		**Instructional Activity:** Using analogies to garden hoses, the variables that determine the resistance in a wire are explored. The lesson begins with students brainstorming about factors that affect resistance; a student volunteer compiles the list on the board. I provide prompts, if necessary. Once the list is complete, several diagrams of wires with varying lengths, diameters, and resistivity values are shown, and students compare the resistance of each.
Apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule ($\Sigma \quad V = 0$) 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 6.4, SP 7.2] Use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit. [LO 5.C.3.3, SP 1.4, SP 2.2] 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]	Knight, Jones, and Field, Chapter 22: "Current and Resistance" Elements of a simple circuit — including bulbs and resistors	**Instructional Activity:** Structural elements of a simple circuit, including bulbs and resistors, are available on each lab table. As the interactive lecture progresses, students assemble both simple series and simple parallel circuits, and they practice drawing circuit diagrams. With each component of the circuit, students develop working definitions of terms such as *conductor*, *load*, *voltage*, *resistor*, *current*, and *battery*. This activity may extend into a second day as the student inquiry progresses.

When I assign an involved calculation for the class to work on, I let the students hold up their calculators for me to check. The first person at each lab table to have the correct response becomes the table leader and is responsible for ensuring that the other table members also arrive at the correct response. I monitor their discussions to correct any misunderstandings.

There are several interpretations of what an energy graph is. The textbook does a good job with this explanation in Chapter 22.

Guiding Questions: ▼ What is the cause of static electricity? ▼ How are electric forces similar to gravitational forces? ▼ How does an electric circuit demonstrate conservation of charge? ▼ What factors affect the resistance of a wire?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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]	Connecting wires, bulbs, switches, resistors, ammeters, voltmeters	**Instructional Activity:** Using the circuit diagrams from the previous activity, students brainstorm and develop an explanation for the electric circuit as an example of conservation of charge. Parallels should be drawn that include at least one other conservation law. I incorporate Kirchhoff's junction rule into this activity, and students add this piece to their understanding of circuits. Students then use the provided materials to construct simple circuits and to explain Kirchhoff's loop rule and the conservation of charge.
	Connecting wires, bulbs, switches, resistors, ammeters, voltmeters	**Formative Assessment:** Students perform calculations of resistance, voltage, and current using Ohm's law on circuit diagrams containing both series and parallel circuits. This could be accomplished with a handout of circuit diagrams or actual models placed on tabletops, or it could be in circuits that students have assembled.
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]	Variety of resistors, connecting wires, voltage sources, voltmeters, ammeters	**Instructional Activity:** Students, working in pairs or in small groups, assemble a simple circuit with a battery and at least two resistors, initially in series and later in parallel, and use ammeters and voltmeters, to support the claim that charge (thus current) is conserved. This activity is also used to construct an energy graph of potential difference against distance around the circuit.
	Voltmeters, ammeters, connecting wires, resistors	**Instructional Activity:** In this lab, students use voltage and ammeter probes to collect data in a simple lab exercise to investigate the relationship between potential difference and current. The significance of this lab lies in the beautiful graph of potential difference versus current that is created.

The feedback occurs as I visit each group and ask questions and/or answer questions that are asked by the students. If more practice is needed, this activity could be extended into a second day, or I make practice worksheets containing circuit diagrams available on my website.

I use every opportunity to create a graph from data collected during a lab exercise. Graphical analysis of data should be a regularly practiced skill. This lab uses probeware to gather some of the same kinds of data that were collected in the earlier lab using the analog meters.

Electric Charge, Current, and Resistance

(continued)

Guiding Questions: ▼ What is the cause of static electricity? ▼ How are electric forces similar to gravitational forces? ▼ How does an electric circuit demonstrate conservation of charge? ▼ What factors affect the resistance of a wire?

Learning Objectives	Materials	Instructional Activities and Assessments
	O'Kuma, Maloney, and Hieggelke, Ranking Task: "Current Carrying Wires with Different Resistances—Net Charge"	**Formative Assessment:** In this task, students rank six lengths of wire, each with a different resistance and current, according to the net electric charge. Individuals work alone for several minutes, then collaboratively as a group, and finally, the table groups share their findings with the whole class.
Apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule ($\sum v = 0$) 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 6.4, SP 7.2]	Easel pads, markers	**Summative Assessment:** Using an easel pad, each group creates a poster explaining Kirchhoff's rules and the conservation laws. These are displayed and peer reviewed. A second portion of the assessment requires students to draw a circuit diagram from a written description and perform requested calculations involving charge, potential difference, and resistance.

I listen to the comments and questions to provide feedback about students' responses and determine if additional instruction is necessary.

This assessment addresses the following guiding questions:

- *How does an electric circuit demonstrate conservation of charge?*
- *What factors affect the resistance of a wire?*

Resources

General Resources

Appel, Kenneth, Clarence Bakken, John Gastineau, and David Vernier. *Physics with Vernier*. Beaverton, OR: Vernier Software & Technology, 2010. This is a lab manual designed for use with the Vernier probes and software.

Knight, Randall D., Brian Jones, and Stuart Field. *College Physics: A Strategic Approach*. 2nd ed. Boston: Addison-Wesley Publishing, 2009.

Knight, Randall D., Brian Jones, Stuart Field, and James H. Andrews. *Student Workbook for College Physics: A Strategic Approach*. 2nd ed. Boston: Addison-Wesley Publishing, 2009.

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

"Part 1: Newton's Laws." ActivPhysics OnLine. Accessed May 9, 2013. http://wps.aw.com/aw_knight_physics_1/17/4389/1123668.cw/index.html. This is a site that guides students through short simulations, providing prompts and instructional assistance.

PASCO Scientific. *Instruction Manual and Experiment Guide for the PASCO scientific Model ME-9435A and ME-9429A: Dynamics Cart Accessory Track Set (1.2 m Version).* Roseville, CA: PASCO Scientific. 1992.

QUEST Learning & Assessment. Accessed May 9, 2013. http://getquest.cns.utexas.edu/. This is an online test bank through the University of Texas at Austin, which I use to assign online problem sets and create worksheets, quizzes, and tests.

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.

Supplementary Resources

PASCO Scientific. *Instruction Manual and Experiment Guide for the PASCO scientific Model ME-9430: Dynamics Cart with Mass*. Roseville, CA: PASCO Scientific, 1992.

Unit 1 (Kinematics in One Dimension) Resources

"1.3 Predicting Motion from Graphs." ActivPhysics OnLine. Accessed May 4, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/DescribingMotion/PredictMotionGraphs/Main.html.

"1.7 Balloonist Drops Lemonade." ActivPhysics OnLine. Accessed May 4, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/DescribingMotion/BalloonistDropsLemonade/Main.html.

"Accelerated Motion: A Data Analysis Approach." PhysicsLAB. Accessed May 4, 2013. http://dev.physicslab.org/Document.aspx?doctype=3&filename=Kinematics_AcceleratedMotionDataAnalysisApproach.xml.

"Accelerated Motion: Practice with Data Analysis." PhysicsLAB. Accessed May 4, 2013. http://dev.physicslab.org/Document.aspx?doctype=5&filename=Kinematics_AcceleratedMotionDataAnalysis.xml.

"The Apollo 15 Hammer–Feather Drop." NASA. Video. Accessed May 20, 2013. http://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_15_feather_drop.html.

"Linear Kinematics Quiz 1." Physics 24/7. Accessed May 4, 2013. http://www.physics247.com/physics-homework-help/linearkinematicsquiz1.php.

Supplementary Resources

"The Law of Falling Bodies." The Mechanical Universe…and Beyond. Video. Accessed March 22, 2013. http://www.learner.org/resources/series42.html?pop=yes&pid=549.

"Mission to the Edge of Space." Red Bull Stratos. Accessed July 31, 2013. http://www.redbullstratos.com/.

Unit 2 (Kinematics in Two Dimensions) Resources

"3.5 Initial Velocity Components." ActivPhysics OnLine. Accessed May 9, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/ProjectileMotion/InitialVelocityComponents/Main.html.

"Components Quiz 1." Physics 24/7. Accessed May 9, 2013. http://www.physics247.com/physics-homework-help/componentsquiz1.php.

"Projectile Motion Quiz 2." Physics 24/7. Accessed May 9, 2013. http://www.physics247.com/physics-homework-help/projectilequiz2.php.

Unit 3 (Newton's First Law and Equilibrium) Resources

"2.1.2 Qualitative Questions: Skydiver." ActivPhysics OnLine. Accessed May 6, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/ForcesMotion/SkyDiver/Main.html.

"Brian Cox Explains the Forces of Nature." Video, 14:01. Accessed May 6, 2013. http://www.guardian.co.uk/science/video/2011/mar/04/brian-cox-forces-nature-video.

"Forces and Newton's Laws." Tiros Educational, Inc. Video, 19:01. Accessed May 6, 2013. http://www.tiros.ca/videos/laws.html.

Supplementary Resources

"Fundamental Forces." The Mechanical Universe…and Beyond. Video. Accessed May 8, 2013. http://www.learner.org/vod/vod_window.html?pid=557.

Unit 4 (Newton's Second Law and Acceleration) Resources

"Inertial vs. Gravitational Mass." PhysicsLAB. Accessed May 7, 2013. http://dev.physicslab.org/Document.aspx?doctype=3&filename=Dynamics_InertialGravitationalMass.xml.

"Net Force Quiz." Physics 24/7. Accessed May 7, 2013. http://www.physics247.com/physics-homework-help/netforce.php.

Supplementary Resources

"Dynamics Quiz 1." Physics 24/7. Accessed May 9, 2013. http://www.physics247.com/physics-homework-help/dynamics_quiz1.php.

Hokin, Samuel. "Skidmark Forensics." The Physics of Everyday Stuff. Accessed May 9, 2013. http://www.bsharp.org/physics/skidmarks.

"Planar Force Quiz." Physics 24/7. Accessed May 9, 2013. http://www.physics247.com/physics-homework-help/planarforcequiz.php.

Unit 5 (Two-Mass Systems and Newton's Third Law) Resources

"2.11 Modified Atwood Machine." ActivPhysics OnLine. Accessed May 7, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/ForcesMotion/ModifiedAtwood/Main.html.

"Combining Kinematics and Dynamics." PhysicsLAB. Accessed May 7, 2013. http://dev.physicslab.org/Document.aspx?doctype=5&filename=Dynamics_CombiningKinematicsDynamics.xml.

"Distinguishing 2nd and 3rd Law Forces." PhysicsLAB. Accessed May 7, 2013. http://dev.physicslab.org/Document.aspx?doctype=5&filename=Dynamics_Distinguishing2nd3rdLawForces.xml.

Newton's second law quiz. DC Physics. Accessed May 7, 2013. http://www.dctech.com/physics/help/tests.php?maketest=yes&selection%5B%5D=motion-newton-second.

"Ropes and Pulleys in Static Equilibrium." PhysicsLAB. Accessed May 7, 2013. http://dev.physicslab.org/Document.aspx?doctype=5&filename=Dynamics_StaticEquilibrium.xml.

"Systems: Two or More Bodies/3rd Law (Newton's Third Law)." MIT OpenCourseWare. Video, 4:56. Accessed May 7, 2013. http://ocw.mit.edu/high-school/physics/newtons-laws-of-motion/systems-two-or-more-bodies-3rd-law/.

Unit 6 (Work and the Conservation of Energy) Resources

"5.1 Work Calculations." ActivPhysics OnLine. Accessed May 6, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/WorkEnergy/WorkCalculations/Main.html.

"5.5 Spring-Launched Bowler." ActivPhysics OnLine. Accessed May 6, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/WorkEnergy/SpringLaunchedBowler/Main.html.

"Bouncing Balls." Department of Physics and Astronomy – University of Hawaii at Manoa. Video. Accesssed May 6, 2013. http://www.phys.hawaii.edu/~teb/java/ntnujava/bouncingBall/bouncingBall.html.

"Conservation of Energy." The Mechanical Universe…and Beyond. Video. Accessed May 6, 2013. http://www.learner.org/resources/series42.html?pop=yes&pid=560#.

"Conservation of Energy." PhysicsQuest. Accessed May 7, 2013. http://physicsquest.homestead.com/quest3ap.html.

"Force vs. Displacement Graphs." PhysicsLAB. Accessed May 8, 2013. http://dev.physicslab.org/Document.aspx?doctype=5&filename=WorkEnergy_ForceDisplacementGraphs.xml.

"A Spring, a Ramp, and a Mass" in the "Work and Energy" section. Davidson Web Physics. Accessed May 7, 2013. http://webphysics.davidson.edu/physlet_resources/bu_semester1/index.html.

"Work Done by a Spring" in the "Work and Energy" section. Davidson Web Physics. Accessed May 6, 2013. http://webphysics.davidson.edu/physlet_resources/bu_semester1/index.html.

Supplementary Resources

Work, Energy, Power: Conservation of Energy Quizzes 1-4. Physics 24/7. Accessed May 9, 2013. http://www.physics247.com/physics-homework-help/index.shtml.

Unit 7 (Systems of Particles and Linear Momentum) Resources

"6.3 Momentum Conservation and Collisions." ActivPhysics OnLine. Accessed May 7, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/Momentum/MomentumConsCollisions/Main.html.

"6.5 Car Collision: Two Dimensions." ActivPhysics OnLine. Accessed May 7, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/Momentum/CarCollisionsTwoDim/Main.html.

"6.7 Explosion Problems." ActivPhysics OnLine. Accessed May 7, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/Momentum/ExplosionProblems/Main.html.

"6.8 Skier and Cart." ActivPhysics OnLine. Accessed May 7, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/Momentum/SkierAndCart/Main.html.

"6.10 Pendulum Person-Projectile Bowling." ActivPhysics OnLine. Accessed May 7, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/Momentum/PendulumPersProjectileBowling/Main.html.

"Collision Lab." PhET. University of Colorado at Boulder. Accessed May 7, 2013. http://phet.colorado.edu/sims/collision-lab/collision-lab_en.html.

Golf ball compression video. Photron High Speed Cameras. Accessed May 6, 2013. http://www.photron.com/index.php?cmd=gallery&cid=12&mv=12_03_golf_ball.

"How to Kick a Rugby Ball in Super Slow Motion – 1000 Frames Per Second." York Smith Productions. Video, 0:35. Accessed July 31, 2013. http://www.youtube.com/watch?v=seg7eLmw5pY.

"Practice: Momentum and Energy #1." PhysicsLAB Online. Accessed May 7, 2013. http://dev.physicslab.org/Document.aspx?doctype=5&filename=Momentum_PracticeMomentumEnergy.xml.

Supplementary Resources

"Ballistic Pendulum." Accessed May 7, 2013. http://www.fisicanimada.net.br/sites/default/files/applets/oscilacoes/pendulo_balistico/sim13.swf.

"Center of Mass Trajectory." MIT VIDEO. Video, 1:31. Accessed May 8, 2013. http://video.mit.edu/watch/center-of-mass-trajectory-4001/.

"Circus Physics: Linear Momentum." PBS. Video, 1:58. Accessed May 9, 2013. http://www.pbs.org/opb/circus/classroom/circus-physics/linear-momentum/.

"Determining the Velocity of a Steel Ball Using a Ballistic Pendulum." Mr. Bigler's MOODLE Site. Video, 1:33. Accessed May 9, 2013. http://www.mrbigler.com/moodle/mod/page/view.php?id=3799.

Hokin, Samuel. "Gun Recoil." The Physics of Everyday Stuff. Accessed May 9, 2013. http://www.bsharp.org/physics/recoil.

"Momentum Quiz 1." Physics 24/7. Accessed May 9, 2013. http://www.physics247.com/physics-homework-help/momentum_quiz1.php.

"Newton's Third Law of Motion: Momentum and Recoil." Accessed May 9, 2013. http://www.dynamicscience.com.au/tester/solutions/war/newton/recoilless.htm.

"Systems of Particles." HippoCampus. Accessed May 9, 2013. http://www.hippocampus.org/HippoCampus/Physics?loadLeftClass=CourseCombination&loadLeftId=15&loadTopicId=2023.

Two-dimensional collisions applet. Accessed May 9, 2013. http://galileoandeinstein.physics.virginia.edu/more_stuff/Applets/Collision/jarapplet.html.

Unit 8 (Simple Harmonic Motion) Resources

No unit-specific resources.

Supplementary Resources

"10 Hooke's Law, Simple Harmonic Oscillator." MIT OpenCourseWare. Video, 49:29. Accessed May 9, 2013. http://ocw.mit.edu/courses/physics/8-01-physics-i-classical-mechanics-fall-1999/video-lectures/lecture-10/.

"Basic Practice with Springs." PhysicsLAB Online. Accessed May 9, 2013. http://dev.physicslab.org/Document.aspx?doctype=5&filename=OscillatoryMotion_BasicSprings.xml.

"Demonstrations of Simple Harmonic Motion." University of California – Irving. Accessed May 9, 2013. http://positron.ps.uci.edu/~dkirkby/music/html/demos/SimpleHarmonicMotion/index.html.

"Masses and Springs." PhET. University of Colorado at Boulder. Accessed May 9, 2013. http://phet.colorado.edu/sims/mass-spring-lab/mass-spring-lab_en.html.

"An Oscillating Spring." Accessed May 9, 2013. http://mmsphyschem.com/oscSpring.html.

Unit 9 (Universal Gravitation and Orbits) Resources

"4.6 Satellites Orbit." ActivPhysics OnLine. Accessed May 8, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/CircularMotion/SatellitesOrbit/Main.html.

"The Apple and the Moon." The Mechanical Universe…and Beyond. Video. Accessed May 8, 2013. http://www.learner.org/vod/vod_window.html?pid=555.

“DIY Podcast: Sports Demo Video Clips.” NASA. Accessed May 9, 2013. http://www.nasa.gov/audience/foreducators/diypodcast/sd-video-index-diy.html.

“Gravitational Field Quiz.” Physics 24/7. Accessed May 9, 2013. http://www.physics247.com/physics-homework-help/gravitationalfield.php.

“Gravity and Orbits.” PhET. University of Colorado at Boulder. Accessed May 8, 2013. http://phet.colorado.edu/en/simulation/gravity-and-orbits.

“Gravity Force Lab.” PhET. University of Colorado at Boulder. Accessed May 8, 2013. http://phet.colorado.edu/en/simulation/gravity-force-lab.

“How to Weigh the Earth.” ScienceOnline. Video, 4:25. Accessed May 9, 2013. http://www.youtube.com/watch?v=9yMQM5AN8mc.

“The Law of Universal Gravitation.” PhysicsLAB Online. Accessed May 9, 2013. http://dev.physicslab.org/Document.aspx?doctype=3&filename=UniversalGravitation_UniversalGravitation.xml.

Supplementary Resources

“Universal Gravitation and Satellites.” PhysicsLAB Online. Accessed May 9, 2013. http://dev.physicslab.org/Document.aspx?doctype=5&filename=UniversalGravitation_Satellites.xml.

Unit 10 (Rotational Motion) Resources

“7.1 Calculating Torques.” ActivPhysics OnLine. Accessed May 9, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/RotMotionStatics/CalculatingTorques/Main.html.

“7.14 Ball Hits Bat.” ActivPhysics OnLine. Accessed May 9, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/RotMotionStatics/BallHitsBat/Main.html.

“7.3 Arm Levers.” ActivPhysics OnLine. Accessed May 9, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/RotMotionStatics/ArmLevers/Main.html.

“Circular Motion.” McGraw Hill Higher Education. Accessed May 9, 2013. http://www.mhhe.com/physsci/physical/giambattista/circular/circular.html.

“Circus Physics: Conservation of Angular Momentum.” PBS. Video, 2:05. Accessed May 8, 2013. http://video.pbs.org/video/1607951704/.

“Rotational Kinematics.” PhysicsLAB Online. Accessed May 9, 2013. http://dev.physicslab.org/Document.aspx?doctype=3&filename=RotaryMotion_RotationalKinematics.xml.

Supplementary Resources

“19: Rotating Rigid Bodies, Inertia, and Axis Theorems.” MIT OpenCourseWare. Video, 41:15. Accessed May 9, 2013. http://ocw.mit.edu/courses/physics/8-01-physics-i-classical-mechanics-fall-1999/video-lectures/lecture-19/.

“Forces and Torques in Muscles and Joints.” Connexions. Accessed May 8, 2013. http://cnx.org/content/m42175/latest/?collection=col11406/latest.

Hokin, Samuel. “Figure Skating Spins.” The Physics of Everyday Stuff. Accessed May 9, 2013. http://www.bsharp.org/physics/spins.

“Torque and Equilibrium.” HippoCampus. Accessed May 9, 2013. http://www.hippocampus.org/homework-help/Physics-B/Circular%20Motion%20and%20Rotation_Torque%20and%20Equilibrium.html.

Unit 11 (Mechanical Waves and Sound) Resources

“10.1 Properties of Mechanical Waves.” ActivPhysics. Accessed May 9, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/Waves/PropertiesMechWaves/Main.html.

"Applet: Doppler Effect." Bauer, W. Accessed May 9, 2013. http://lectureonline.cl.msu.edu/~mmp/applist/doppler/d.htm.

Hwang, Fu-Kwun. "Superposition Principle of Wave." NTNUJava Virtual Physics Laboratory. Accessed May 9, 2013. http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=19.msg124#msg124.

Kurtus, Ron. "Beat Frequencies in Sound." School for Champions. Accessed May 9, 2013. http://www.school-for-champions.com/science/sound_beat_frequencies.htm.

"Longitudinal and Transverse Wave Motion." Russell, Daniel A. Accessed May 9, 2013. http://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html.

"Ripple Tank." Accessed May 9, 2013. http://www.falstad.com/ripple/.

"Standing Wave (Explanation by Superposition with the Reflected Wave)." Walter Fendt. Accessed May 9, 2013. http://www.walter-fendt.de/ph14e/stwaverefl.htm.

"Wave on a String." PhET. University of Colorado at Boulder. Accessed May 9, 2013. http://phet.colorado.edu/sims/wave-on-a-string/wave-on-a-string_en.html.

"Waveform and Vibration Graphs #1." PhysicsLAB Online. Accessed May 9, 2013. http://dev.physicslab.org/Document.aspx?doctype=5&filename=WavesSound_WaveformVibrationGraphs1.xml.

Supplementary Resources

"10.7 Beats and Beat Frequency." ActivPhysics. Accessed May 9, 2013. http://media.pearsoncmg.com/bc/aw_young_physics_11/pt1a/Media/Waves/BeatFrequency/Main.html.

"Periodic Wave Phenomena." Accessed May 9, 2013. http://lvweb.lvcsd.k12.ny.us/schools/Teachers/stella/Copy%20of%20School%20Island/Periodic%20Wave%20Phenomena.pdf.

Russell, Daniel A. "Reflection from an Impedance Discontinuity and the Standing Wave Ratio." The Pennsylvania State University. Accessed May 9, 2013. http://www.acs.psu.edu/drussell/Demos/SWR/SWR.html.

"Standing Waves on a String." Brooklyn College. Accessed May 9, 2013. http://depthome.brooklyn.cuny.edu/physics/lab/phy1/StandingWaves.pdf.

"Wave Basics." HippoCampus. Accessed May 9, 2013. http://www.hippocampus.org/Physics?loadLeftClass=CourseCombination&loadLeftId=15&loadTopicId=2154.

"Waveform and Vibration Graphs #2." PhysicsLAB Online. Accessed May 9, 2013. http://dev.physicslab.org/Document.aspx?doctype=5&filename=WavesSound_WaveformVibrationGraphs2.xml.

Unit 12 (Electric Charge, Current, and Resistance) Resources

"How Shocking." PBS. Accessed May 9, 2013. http://www.pbs.org/benfranklin/shocking/index.html.

Karlsson, Magnus. "Millikan's Oil Drop Experiment." Rutgers University. Accessed May 9, 2013. http://www.physics.rutgers.edu/~jgoett/millikan/millikan.html.

Supplementary Resources

"Ben Franklin Sparks Electricity." The History Channel. Accessed May 9, 2013. http://www.history.com/videos/ben-franklin-sparks-electricity#ben-franklin-sparks-electricity.

Haynie, Tom. "Measuring e Using the Millikan Apparatus." Accessed May 9, 2013. http://webphysics.davidson.edu/alumni/ToHaynie/OilDrop/oiltable.htm.

"Power in Electric Circuits." All About Circuits. Accessed May 9, 2013. http://www.allaboutcircuits.com/vol_1/chpt_2/3.html.