Kenilworth Public Schools

Curriculum Guide

Content Area: AP Physics
Grade: 12
BOE Approved: 4/6/20

Revision Date: N/A
Submitted by: Phil giordano
BOE Revision Approved: N/A

Advanced Placement Physics Grade 12 Scope and Sequence

Unit 1- Kinematics	Unit 2- Dynamics	Unit 3- Circular Motion and Gravity	Unit 4- Energy	Unit 5- Momentum
Weeks 1-4	Weeks 5-9	Weeks 10-11	Weeks 12-16	Weeks 17-20
Unit Description: The world is in a constant state of motion. To understand the world, students must first understand movement. Unit 1 introduces students to the study of motion and serves as a foundation for all of AP Physics 1 by beginning to explore the complex idea of acceleration and showing them how representations can be used to model and analyze scientific information as it relates to the motion of objects. By studying kinematics, students will learn to represent motion—both uniform and accelerating—in	*Unit Description:* In Unit 2, students are introduced to the term force, which is the interaction of an object with another object. Part of the larger study of dynamics, forces are used as the lens through which students analyze and come to understand a variety of physical phenomena. This is accomplished by revisiting and building upon the representations presented in Unit 1, specifically the introduction to the free-body diagram. Translation, however, is key in this unit: Students must be able to portray the same	*Unit Description:* In Unit 3, students will continue to enhance their understanding of the physical world using models and representations to create a more complete and complex model of motion, particularly as it relates to gravitational mass and inertial mass. Again, translation and connections are essential—students must be able to use content and science practices from the previous two units and apply them in	*Unit Description:* In Unit 4, students will be introduced to the idea of conservation as a foundational model of physics, along with the concept of work as the agent of change for energy. As in earlier units, students will once again utilize both familiar and new models and representations to analyze physical situations, now with force or energy as major components. Students will be encouraged to call upon their knowledge of Units 1–4 to determine the most appropriate technique and will be challenged	*Unit Description:* Unit 5 introduces students to the relationship between force, time, and momentum via calculations, data analysis, designing experiments, and making predictions. Students will learn how to use new models and representations to illustrate the law of the conservation of momentum of objects and systems while simultaneously building on their knowledge of previously studied representations.

narrative, graphical, and/or mathematical forms and from different frames of reference. These representations will help students analyze the specific motion of objects and systems while also dispelling some common misconceptions they may have about motion, such as exclusively using negative acceleration to describe an object slowing down. Additionally, students will have the opportunity to go beyond their traditional understanding of mathematics. Instead of solving equations, students will use them to support their reasoning and tighten their grasp on the laws of physics. Lastly, students will begin making predictions about motion and justifying claims with evidence by exploring the relationships between the physical	object–force interactions through different graphs, diagrams, and mathematical relationships. Students will continue to make meaning from models and representations that will help them further analyze systems, the interactions between systems, and how these interactions result in change. Alongside mastering the use of specific force equations, Unit 2 also encourages students to derive new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. The skill of making predictions will be nurtured throughout the course to help students craft sound scientific arguments.	different ways. While it's essential that students are able to calculate numerical answers to questions, it is more important that they can combine mathematical representations to make new representations that more accurately describe natural phenomena. For example, students should be comfortable combining equations for uniform circular motion with gravitational equations to describe the circular path of a satellite circling a planet. It is also vital that students are given opportunities to think about and discuss the impact that changes or modifications have on physical scenarios. For example, students	to understand the limiting factors of each. Describing, creating, and using these representations will also help students grapple with common misconceptions that they may have about energy, such as whether or not a single object can "have" potential energy. A thorough understanding of these energy models will support students' ability to make predications—and ultimately justify claims with evidence—about physical situations. This is crucial, as the mathematical models and representations used in Unit 4 will mature throughout the course and appear in subsequent units. As students' comprehension of energy (particularly kinetic, potential, and microscopic internal energy) evolves, they will begin to connect and relate knowledge	Using the law of the conservation of momentum to analyze physical situations gives students a more complete picture of forces and leads them to revisit their misconceptions surrounding Newton's third law. Students will also have the opportunity to make connections between the conserved quantities of momentum and energy to determine under what conditions each quantity is conserved. It's essential that students are not only comfortable solving numerical equations (such as the speed of a system after an inelastic collision) but also confident in their ability to discuss when momentum is conserved and how the type of collision

quantities of acceleration, velocity, position, and time. This is an important starting point for students, as these fundamental science practices will spiral throughout the course and appear in multiple units.		should be able to use mathematical and graphical representations to determine how doubling the distance of a satellite from a planet will change the period of orbit and then justify their answer with evidence and reasoning. Specific preconceptions will be addressed in this unit, such as the idea of a centrifugal force. Students will also have opportunities to wrestle with the idea of field models, which will be expanded upon in Unit 8.	across scales, concepts, and representations, as well as across disciplines, particularly physics, chemistry, and biology.	affects the outcome. Threading such connections between physical quantities is fundamental to understanding the broader relationship between this unit and the rest of the course. Students will have more opportunities to apply conservation laws to make predictions and justify claims in Unit 7 when they are introduced to rotational quantities.

Unit Targets:	Unit Targets:	Unit Targets:	Unit Targets:	Unit Targets:
Express the motion of an object using narrative, mathematical, and graphical representations. Design an experimental investigation of the motion of an object. Analyze experimental data describing the motion of an object and be able to express the results of the analysis using narrative, mathematical, and graphical representations. Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively. Make predictions about the motion of a	Design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration. Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. 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. Challenge a claim that an object can exert a force on itself. Describe a force as an	Use Newton's law of gravitation to calculate the gravitational force that two objects exert on each other and use that force in contexts other than orbital. Use Newton's law of gravitation to calculate the gravitational force. Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. Apply $F = mg$ to calculate gravitational force. Evaluate, using given data, whether all the forces on a system or whether all the parts of a system have been identified Design a plan to collect and analyze data for motion (static, constant,	Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. 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. Use net force and velocity vectors to determine qualitatively whether the kinetic energy of an object would increase, decrease, or remain unchanged. Use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether the kinetic energy of that object would increase, decrease, or	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. 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. 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. 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 collision Design a plan for collecting data to investigate the

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. 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.	interaction between two objects, and identify both objects for any force. Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action- reaction pairs of forces. 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. Design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurement, and carry out an analysis to determine the relationship between	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. Re-express a free-body diagram representation into a mathematical representation, and solve the mathematical representation for the acceleration of the object.	remain unchanged. Apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object 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 Predict changes in the total energy of the system due to changes in position and speed of objects or frictional interactions within the system. 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. Apply the concepts of conservation of energy	relationship between changes in momentum and the average force 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.). 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. 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. Perform an analysis on data presented as a force-time graph and predict the outcome. Define open and closed systems for everyday situations and apply

	the net force and the vector sum of the individual forces. Re-express a free-body diagram into a mathematical representation, and solve the mathematical representation for the acceleration of the object. Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively. 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. Use visual or mathematical representations of the forces between objects in a system to predict whether or not there		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. Create 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. 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. Describe and make qualitative and/or quantitative predictions about everyday examples of systems	conservation concepts for energy change and linear motion Make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions. 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 qualitatively in two-dimensional

	will be a change in the center-of-mass velocity of that system.		with internal potential energy. Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. 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. Describe and make predictions about the internal energy of systems. Calculate changes in kinetic energy and potential energy of a system using information from representations of that system. Design an experiment and analyze data to determine how a force exerted on an object or	situations. 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. 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. Classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and

			system does work on the object or system as it moves through a distance. 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. 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. 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)	restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. 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. 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. Apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. Analyze data that verify conservation of

			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.	momentum in collisions with and without an external frictional force. Classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values.

Advanced Placement Physics Grade 12 Scope and Sequence

Simple Harmonic Motion	Torque and Rotational Motion	Electrical Charge and Electrical Force	DC Circuits	Mechanical Waves and Sound
Weeks 21-22	Weeks 23-26	Week 27-28	Weeks 29-32	Weeks 33-38
Unit Description: In Unit 6, students will continue to use the same tools, techniques, and models that they have been using throughout this course. However, they will now use them to analyze a new type of motion: simple harmonic motion. Although simple harmonic motion is unique, students will learn that even in new situations, the fundamental laws of physics remain the same. Energy bar	*Unit Description:* Unit 7 completes the study of mechanical physics by introducing students to torque and rotational motion. Although these topics present more complex scenarios, the tools of analysis remain the same: The content and models explored in the first six units of AP Physics 1 set the foundation for Unit 7. During their study of torque and rotational motion, students will be confronted with different ways of thinking about and	*Unit Description:* Although Unit 8 presents students with physical phenomena that are difficult or impossible to directly observe, the concepts of electric charge and electric force are the cornerstones of the study of electricity and magnetism. As in earlier units, the foundation of this unit includes the study of relationships and change: Students are expected to be able to discuss what happens to force when there is a change in the separation between	*Unit Description:* In Unit 9, students will draw on their knowledge of electricity and apply it to the conservation of charge in electric circuits. This unit will push students to move beyond mathematically solving for current, resistance, and voltage and will challenge them to make connections between system interactions and the changes that result from these interactions. For example, students	*Unit Description:* In Unit 10, students will move away from the main themes of the previous units and learn about mechanical waves. Although concepts like oscillation, energy, and motion carry over into the study of waves, students will be introduced to new tools to communicate scientific phenomena and solve scientific models. Standing wave models, for example, are applied in Unit 10 to support a more in-depth

charts, as well as free-body diagrams, become increasingly important as students work toward determining which model is most appropriate for a given physical situation. Preconceptions—such as the relationship between the amplitude and period of oscillation—will also be addressed to provide students with a more nuanced awareness of simple harmonic motion. Students are expected to use the content knowledge they gained in the first five units to make and defend claims while also making connections in and across the content topics and big ideas. Because Unit 6 is the first unit in which	modeling forces. As in previous units, it's critical that students are given opportunities to create and use representations and models to make predictions and justify claims. It's equally important that students are comfortable deriving new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. Unit 7 also focuses on the mathematical practice of estimating quantities that can describe natural phenomena. For example, students need to be able to estimate the torque on an object caused by various forces in comparison to other situations. Although	charges or the magnitude of charges. It's essential for students to be able to use mathematics and mathematical relationships as evidence for claims, to analyze someone else's mathematical derivation, and/or to explain their own mathematical derivation in a narrative. Throughout this unit, students will also apply and make predictions about conserved quantities, which will be further developed and applied in Unit 9. Helping students practice the skill of constructing scientific explanations of phenomena based on scientific practices should also be a focus of Unit 8, as it helps students readily make comprehensive	must not only be able to calculate the resistance of a light bulb in a circuit; they must also be able to articulate the impact on other bulbs in the circuit if that light bulb is removed. Throughout the unit, it is essential that students have opportunities to create and use representations and models, especially as evidence to make predictions, justify claims, and overcome any preconceived notions about circuits. It is also important that students develop an understanding of the language used in Unit 8. Correctly using vocabulary terms such as "voltage," "current," and "energy" is essential to accurately describe, analyze, and reason with content	knowledge of musical instruments and sounds. Because knowledge of mechanical waves is essential for understanding a wide range of physical phenomena (including light and the wave properties of matter), students will have several opportunities in Unit 10 to connect and relate knowledge across various scales, concepts, and representations. Being able to identify and describe the relationships between physical quantities and use these relationships as justification for claims are equally essential. Although its content remains distinct from earlier units, Unit 10 presents concepts that will help students

students possess all the tools of force, energy, and momentum conservation, it’s important that teachers scaffold lessons to help them develop a better understanding of each fundamental physics principles as well as its limitations. Throughout this unit, students will be asked to create force, energy, momentum, and position versus time graphs for a single scenario and to make predictions based on their representations. Students will enhance their study of motion when they learn about oscillatory motion in Unit 10.	this particular science practice doesn’t appear often in AP Physics 1, it nonetheless is an important conceptual skill for students to be able to compare estimated values of physical quantities. Throughout this unit, students will have opportunities to compare and connect their understanding of linear and rotational motion, dynamics, energy, and momentum to make meaning of these concepts as a whole, rather than as distinct and separate units.	predictions about new phenomena. Students will also use familiar representations and models to make predictions and justify claims. These will help students dispel some of the common misconceptions that they may continue to have about forces, such as two charged objects with different net charges applying different magnitude forces on the other object. The content and ideas presented in Unit 8 set a solid foundation for students to be able to investigate and understand both DC circuits, in Unit 9, and the topics of electricity and magnetism, in AP Physics 2.	presented in this course. By helping students relate theoretical models of electricity to real circuits, Unit 9 sets the stage for AP Physics C: Electricity and Magnetism, which explores circuits in greater depth.	succeed in later physics courses. Students who take AP Physics 2 will further investigate the ideas presented in Unit 10 through their additional study of mechanical waves.

Unit Targets: Predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. 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. Analyze data to identify qualitative and 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 and use those data to determine the value of an unknown. Construct a qualitative	*Unit Targets:* Express the motion of an object using narrative, mathematical, and graphical representations. Express the motion of an object using narrative, mathematical, and apply to constant acceleration situations. Compare the torques on an object caused by various forces. Estimate the torque on an object caused by various forces in comparison with other situations. Design an experiment and analyze data testing a question about torques in a balanced rigid system. Calculate torques on a two-dimensional system in static equilibrium by examining a representation or model (such as a diagram or physical construction). Use representations of	*Unit Targets:* Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations Make claims about natural phenomena based on conservation of electric charge. 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. Construct an explanation of the two-charge model of electric charge. Use Coulomb's Law qualitatively and quantitatively to make predictions about interactions between collections of electric point charges. Connect the concepts of	*Unit Targets:* Make claims about natural phenomena based on conservation of electric charge. 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. Choose and justify the selection of data needed to determine resistivity for a given material. 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). Apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of	*Unit Targets:* 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. Describe representations of transverse and longitudinal waves Describe sound in terms of transfer of energy and momentum in a medium and relate the concepts to everyday examples. Use graphical representation of a periodic mechanical wave to determine the amplitude of the wave. 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. Use a graphical representation of a

and/ or quantitative explanation of oscillatory behavior given evidence of a restoring force. 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. Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. Make quantitative calculations of the internal potential energy of a system from	the relationship between force and torque. 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. Plan data-collection and analysis strategies designed to test the relationship between a torque exerted on an object 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 In an unfamiliar context or using representations beyond equations, justify the selection of a mathematical routine to solve for the change in	gravitational force and electric force to compare similarities and differences between forces.	Kirchhoff's loop rule ($\sum \Delta V = 0$) in a circuit with only a battery and resistors either in series or in, at most, one pair of parallel branches. 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. 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. Design an investigation	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 Use a visual representation of a periodic mechanical wave to determine the wavelength of the wave Design an experiment to determine the relationship between periodic wave speed wavelength, and frequency and relate these concepts to everyday examples Create or use a wave front diagram to demonstrate or interpret qualitatively the observed frequency of a wave, dependent on relative motions of source and observer Use representations of individual pulses and construct representations to model the interaction of two wave pulses to

a description or diagram of that system. 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 Describe and make predictions about the internal energy of systems. Calculate changes in kinetic energy and potential energy of a system using information from representations of that system	angular momentum of an object caused by torques exerted on the object 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. 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. 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		of an electrical circuit with one or more resistors in which evidence of conservation of electric charge can be collected and analyzed. Use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit	analyze the superposition of two pulses Design a suitable experiment and analyze data illustrating the superposition of mechanical waves (only for wave pulses or standing waves 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. 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 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

	counterclockwise with respect to a well-defined axis of rotation, and refine the research question based on the examination of data. 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. 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. Use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular			quantitatively 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. Plan data-collection strategies, predict the outcome based on the relationship under test, perform data analysis, evaluate evidence compared with 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. Describe representations and models of situations in which standing waves result from the addition of incident and reflected waves confined to a region. Challenge with evidence the claim that the wavelengths of

	momentum. 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. The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted. Make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque. Make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero.			standing waves are determined by the frequency of the source, regardless of the size of the region. 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. Use a visual representation to explain how waves of slightly different frequency give rise to the phenomenon of beats.

	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.			

Advanced Placement Physics Grade 12 Framework

Unit Title: Kinematics	
Unit Summary: The world is in a constant state of motion. To understand the world, students must first understand movement. Unit 1 introduces students to the study of motion and serves as a foundation for all of AP Physics 1 by beginning to explore the complex idea of acceleration and showing them how representations can be used to model and analyze scientific information as it relates to the motion of objects. By studying kinematics, students will learn to represent motion—both uniform and accelerating—in narrative, graphical, and/or mathematical forms and from different frames of reference. These representations will help students analyze the specific motion of objects and systems while also dispelling some common misconceptions they may have about motion, such as exclusively using negative acceleration to describe an object slowing down. Additionally, students will have the opportunity to go beyond their traditional understanding of mathematics. Instead of solving equations, students will use them to support their reasoning and tighten their grasp on the laws of physics. Lastly, students will begin making predictions about motion and justifying claims with evidence by exploring the relationships between the physical quantities of acceleration, velocity, position, and time. This is an important starting point for students, as these fundamental science practices will spiral throughout the course and appear in multiple units.	
Primary Interdisciplinary Connections: MP.2, MP.4, HSN-Q.A.1, HSN-Q.A.2, HSN-Q.A.3, HSA-SSE.A.1, HSA-SSE.B.3, HSA-CED.A.1, HSA-CED.A.2, HSA-CED.A.4, HSF-IF.C.7, HSS-ID.A.1	
21st Century Career and Life Themes: Creativity and Innovation, Critical Thinking and Problem Solving, Communication and Collaboration, Information Literacy, Media Literacy	
Learning Targets	
NJSLS Standards: HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-6	
Technology Standards: 8.1.12.A.1, 8.1.12.A.2, 8.1.12.A.3, 8.1.12.A.4, 8.1.12.A.5, 8.1.P.B.1, 8.1.2.B.1, 8.1.5.B.1, 8.1.8.B.1, 8.1.2.C.1, 8.1.12.C.1, 8.1.12.D.5, 8.1.12.E.1, 8.1.12.F.1, 8.2.12.A.1, 8.2.12.C.3, 8.2.12.C.4, 8.2.12.C.5, 8.2.12.E.1	
ELA Companion Standards: RST.11-12.1, RST.11-12.7, WHST.9-12.2, WHST.9-12.7, WHST.11-12.8, WHST.11-12.9	
Content Statements:	
1	Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
2	Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
3	Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
4	Communicate scientific and technical information about why the molecular-level structure is

important in the functioning of designed materials.

Big Idea: The interactions of an object with other objects can be described by forces and interactions between systems can result in changes in those systems.

Unit Essential Questions:	**Unit Enduring Understandings:**
• How can the motion of objects be predicted and/or explained? • Can equations be used to answer questions regardless of the questions' specificity? • How can the idea of frames of reference allow two people to tell the truth yet have conflicting reports? • How can we use models to help us understand motion? • Why is the general rule for stopping your car "when you double your speed, you must give yourself four times as much distance to stop?"	• All forces share certain common characteristics when considered by observers in inertial reference frames. • The acceleration of the center mass of a system is related to the net force exerted on a system.

Unit Learning Targets

Students will…

- Express the motion of an object using narrative, mathematical, and graphical representations.
- Design an experimental investigation of the motion of an object.
- Analyze experimental data describing the motion of an object and be able to express the results of the analysis using narrative, mathematical, and graphical representations.
- Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively.
- 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.
- 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.

Evidence of Learning

Summative Assessment: Labs, Unit Tests, Benchmarks

Formative Assessments:

- Quizzes
- Section Tests
- Take home assignments

Lesson Plans	
Activities/Interdisciplinary Connections	*Timeframe*
• Have students find the acceleration of a yo-yo as it falls and unwinds using only a meterstick and stopwatch. Students then draw (with correct shapes and scales) distance, speed, and acceleration versus time graphs. • Each group is given a spring-loaded ball launcher and a meterstick. Students launch the ball horizontally from a known height and then predict where it will land on the floor when fired at a given angle from the floor. Have students articulate subtasks and then perform each one. • Show a curvy *x* versus *t* graph, a *v* versus *t* graph made of connected straight-line segments, or an *a* versus *t* graph made of horizontal steps. Have students sketch the other two graphs and either walk them out along a line or move a cart on a track to demonstrate the motion (the track can be tilted slightly to provide constant acceleration in either direction). • Students throw/project a ball from the second or third story to the ground and measure the ball's initial height, horizontal distance, and time in the air. From this, students calculate initial velocity components and draw (with scales) horizontal/vertical position/velocity/ acceleration versus time graphs. • Give each group a pull-back toy car. Students lay out strips of paper 0.5 m apart and take a phone video of the car as it is released, speeds up, and slows down. Using a frame-by- frame review app to get the time each strip is passed to get *x* versus *t* data, have students make *v* versus *t* data tables out of this, and graph both.	4 weeks
Teacher Resources	*Teacher Note*
• Lab equipment, computers, analysis programs, projectors	

Differentiating Instruction: Students with Disabilities, English Language Learners, and Gifted & Talented Students
Examples of Strategies and Practices that Support Students with Disabilities: • Use of visual and multisensory formats

• Use of assisted technology
• Use of prompts
• Modification of content and student products
• Testing accommodations
• Authentic assessments

Examples of Strategies and Practices that Support Gifted & Talented Students:
• Adjusting the pace of lessons
• Curriculum compacting
• Inquiry-based instruction
• Independent study
• Higher-order thinking skills
• Interest-based content
• Student-driven instruction
• Real-world problems and scenarios

Examples of Strategies and Practices that Support English Language Learners:
• Pre-teaching of vocabulary and concepts
• Visual learning, including graphic organizers
• Use of cognates to increase comprehension
• Teacher modeling
• Pairing students with beginning English language skills with students who have more advanced English language skills
• Scaffolding
•Word walls
•Sentence frames
•Think-pair-share
•Cooperative learning groups

Advanced Placement Physics Grade 12 Framework

Unit Title: Dynamics	
Unit Summary: In Unit 2, students are introduced to the term force, which is the interaction of an object with another object. Part of the larger study of dynamics, forces are used as the lens through which students analyze and come to understand a variety of physical phenomena. This is accomplished by revisiting and building upon the representations presented in Unit 1, specifically the introduction to the free-body diagram. Translation, however, is key in this unit: Students must be able to portray the same object–force interactions through different graphs, diagrams, and mathematical relationships. Students will continue to make meaning from models and representations that will help them further analyze systems, the interactions between systems, and how these interactions result in change. Alongside mastering the use of specific force equations, Unit 2 also encourages students to derive new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. The skill of making predictions will be nurtured throughout the course to help students craft sound scientific arguments.	
Primary Interdisciplinary Connections: MP.2, MP.4, HSN-Q.A.1, HSN-Q.A.2, HSN-Q.A.3, HSA-SSE.A.1, HSA-SSE.B.3, HSA-CED.A.1, HSA-CED.A.2, HSA-CED.A.4, HSF-IF.C.7, HSS-ID.A.1	
21st Century Career and Life Themes: Creativity and Innovation, Critical Thinking and Problem Solving, Communication and Collaboration, Information Literacy, Media Literacy	
Learning Targets	
NJSLS Standards: HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4, HS-PS2-6	
Technology Standards: 8.1.12.A.1, 8.1.12.A.2, 8.1.12.A.3, 8.1.12.A.4, 8.1.12.A.5, 8.1.P.B.1, 8.1.2.B.1, 8.1.5.B.1, 8.1.8.B.1, 8.1.2.C.1, 8.1.12.C.1, 8.1.12.D.5, 8.1.12.E.1, 8.1.12.F.1, 8.2.12.A.1, 8.2.12.C.3, 8.2.12.C.4, 8.2.12.C.5, 8.2.12.E.1	
ELA Companion Standards: RST.11-12.1, RST.11-12.7, WHST.9-12.2, WHST.9-12.7, WHST.11-12.8, WHST.11-12.9	
Content Statements:	
1	Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
2	Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
3	Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
4	Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
5	Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Big Idea: Objects and systems have properties such as mass and charge. Systems may have internal structure. Fields existing in space can be used to explain interactions. The interactions of an object with other objects can be described by forces. Interactions between systems can result in changes in those systems.

Unit Essential Questions:	**Unit Enduring Understandings:**
• How can the properties of internal and gravitational mass be experimentally verified to be the same? • How do you decide what to believe about scientific claims? • How does something we cannot see determine how an object behaves? • Why is the acceleration due to gravity constant on Earth's surface? • Are different kinds of forces *really* different? • How can Newton's laws of motion be used to predict the behavior of objects? • Why does the same push change the motion of a shopping cart more than the motion of a car?	• The internal structure of a system determines many properties of the system. • A gravitational field is caused by an object with mass. • At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. • Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles. • All forces share certain common characteristics when considered by observers in inertial reference frames. • Classically, the acceleration of an object interacting with other objects can be predicted by using a=F/m. • The acceleration of the center of mass of a system is related to the net force exerted on the system.

Unit Learning Targets

Students will…

- Design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration.
- Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation.
- 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.
- Challenge a claim that an object can exert a force on itself.
- Describe a force as an interaction between two objects, and identify both objects for any force.
- Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action- reaction pairs of forces.
- 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.
- Design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurement, and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces.
- Re-express a free-body diagram into a mathematical representation, and solve the mathematical representation for the acceleration of the object.
- Use representations of the center of mass of an isolated two-object system to analyze the motion

of the system qualitatively and semi-quantitatively.

- 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.
- 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.

Evidence of Learning

Summative Assessment: Labs, Unit Tests, Benchmarks

Formative Assessments:

- Quizzes
- Section Tests
- Take home assignments

Lesson Plans

Activities/Interdisciplinary Connections	*Timeframe*
• Have students consider an accelerating two-object system from everyday life (e.g., person pushes a shopping cart, car pulls a trailer). Have them draw the forces on one object, then on the other, and then the external forces acting on the two-object system. • Have students measure the coefficient of static friction of their shoe on a wood plank or metal track. Level 1: Use a spring scale. Level 2: Use a pulley, a spring, a toy bucket, and an electronic balance. Level 3: Use a protractor. • Give students a yo-yo, a low mass, low friction pulley, 50 paper clips, and a scale. Have them find the acceleration of the falling, unrolling yo-yo and then determine the mass of the paper clips to attach to the free end of the string so that the paper clips stay at rest even as the yo-yo falls and the string passes over the pulley. • Student A writes a Newton's second law equation either with symbols or plugged-in numbers including units. Student B must then describe a situation that the equation applies to, including the object's velocity direction and how velocity is changing, a diagram, and a free-body diagram. • Students take some force-related problem from the homework or textbook (one that requires setting up Newton's second law and maybe more). Students write out a detailed solution that has exactly *one*	4 weeks

mistake in it (not a calculation error). Post everyone's problems/ solutions, and then ask students to identify everyone else's errors. The last student to have his or her error found wins.	
Teacher Resources	*Teacher Note*
• Lab equipment, computers, analysis programs, projectors	

Differentiating Instruction: Students with Disabilities, English Language Learners, and Gifted & Talented Students

Examples of Strategies and Practices that Support Students with Disabilities:
- Use of visual and multisensory formats
- Use of assisted technology
- Use of prompts
- Modification of content and student products
- Testing accommodations
- Authentic assessments

Examples of Strategies and Practices that Support Gifted & Talented Students:
- Adjusting the pace of lessons
- Curriculum compacting
- Inquiry-based instruction
- Independent study
- Higher-order thinking skills
- Interest-based content
- Student-driven instruction
- Real-world problems and scenarios

Examples of Strategies and Practices that Support English Language Learners:
- Pre-teaching of vocabulary and concepts
- Visual learning, including graphic organizers
- Use of cognates to increase comprehension
- Teacher modeling
- Pairing students with beginning English language skills with students who have more advanced English language skills
- Scaffolding
- Word walls
- Sentence frames
- Think-pair-share
- Cooperative learning groups

Advanced Placement Physics Grade 12 Framework

Unit Title: Circular Motion and Gravity	
Unit Summary: In Unit 3, students will continue to enhance their understanding of the physical world using models and representations to create a more complete and complex model of motion, particularly as it relates to gravitational mass and inertial mass. Again, translation and connections are essential—students must be able to use content and science practices from the previous two units and apply them in different ways. While it's essential that students are able to calculate numerical answers to questions, it is more important that they can combine mathematical representations to make new representations that more accurately describe natural phenomena. For example, students should be comfortable combining equations for uniform circular motion with gravitational equations to describe the circular path of a satellite circling a planet. It is also vital that students are given opportunities to think about and discuss the impact that changes or modifications have on physical scenarios. For example, students should be able to use mathematical and graphical representations to determine how doubling the distance of a satellite from a planet will change the period of orbit and then justify their answer with evidence and reasoning. Specific preconceptions will be addressed in this unit, such as the idea of a centrifugal force. Students will also have opportunities to wrestle with the idea of field models, which will be expanded upon in Unit 8.	
Primary Interdisciplinary Connections: MP.2, MP.4, HSN-Q.A.1, HSN-Q.A.2, HSN-Q.A.3, HSA-SSE.A.1, HSA-SSE.B.3, HSA-CED.A.1, HSA-CED.A.2, HSA-CED.A.4, HSF-IF.C.7, HSS-ID.A.1	
21st Century Career and Life Themes: Creativity and Innovation, Critical Thinking and Problem Solving, Communication and Collaboration, Information Literacy, Media Literacy	
Learning Targets	
NJSLS Standards: HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4, HS-PS2-6	
Technology Standards: 8.1.12.A.1, 8.1.12.A.2, 8.1.12.A.3, 8.1.12.A.4, 8.1.12.A.5, 8.1.P.B.1, 8.1.2.B.1, 8.1.5.B.1, 8.1.8.B.1, 8.1.2.C.1, 8.1.12.C.1, 8.1.12.D.5, 8.1.12.E.1, 8.1.12.F.1, 8.2.12.A.1, 8.2.12.C.3, 8.2.12.C.4, 8.2.12.C.5, 8.2.12.E.1	
ELA Companion Standards: RST.11-12.1, RST.11-12.7, WHST.9-12.2, WHST.9-12.7, WHST.11-12.8, WHST.11-12.9	
Content Statements:	
1	Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
2	Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
3	Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
4	Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to

	describe and predict the gravitational and electrostatic forces between objects.
5	Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Big Idea: Objects and systems have properties such as mass and charge. Systems may have internal structure. Fields existing in space can be used to explain interactions. The interactions of an object with other objects can be described by forces. Interactions between systems can result in changes in those systems.

Unit Essential Questions:

- How does changing the mass of an object affect the gravitational force?
- Why is a refrigerator hard to push in space?
- Why do we feel pulled toward Earth but not toward a pencil?
- How can the acceleration due to gravity be modified?
- How can Newton's laws of motion be used to predict the behavior of objects?
- How can we use forces to predict the behavior of objects and keep us safe?
- How is the acceleration of the center of mass of a system related to the net force exerted on the system?
- Why is it more difficult to stop a fully loaded dump truck than a small passenger car?

Unit Enduring Understandings:

- A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces), as well as a variety of other physical phenomena.
- Certain types of forces are considered fundamental.
- At the macroscopic level, forces can be categorized as either long-range (action-at- a-distance) forces or contact forces.
- A gravitational field is caused by an object with mass.
- Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
- Classically, the acceleration of an object interacting with other objects can be predicted by using the formula a=F/m.
- All forces share certain common characteristics when considered by observers in inertial reference frames.

Unit Learning Targets

Students will…

- Use Newton's law of gravitation to calculate the gravitational force that two objects exert on each other and use that force in contexts other than orbital.
- Use Newton's law of gravitation to calculate the gravitational force.
- Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces.
- Apply $F = mg$ to calculate gravitational force.

- Evaluate, using given data, whether all the forces on a system or whether all the parts of a system have been identified.

- 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.
- Re-express a free-body diagram representation into a mathematical representation, and solve the mathematical representation for the acceleration of the object.

Evidence of Learning

Summative Assessment: Labs, Unit Tests, Benchmarks

Formative Assessments:

- Quizzes
- Section Tests
- Take home assignments

Lesson Plans

Activities/Interdisciplinary Connections	*Timeframe*
• Have students use the "My Solar System" PhET applet to create circular orbits of varying radii around the central star and record radius, period, and planet mass for various trials. Next, have them calculate the speed using $v = 2\pi r/T$ and force using $F = mv^2/r$. Using the data, students show that gravitational force is directly proportional to mass and inversely proportional to radius. • Ask students to consider two identical objects moving in circles (or parts of circles) of different radii. Ask them to think of a situation where the object with the smaller radius has a greater net force and another situation where the object with the larger radius has a greater net force. • Describe something a driver could be doing in a car (e.g., "turning the steering wheel to the right while pressing the brake"). Have students walk out the motion while holding out one arm representing the velocity vector and the other arm representing the acceleration vector.	2 weeks

• Find a data table on stopping distance. Have students determine the coefficient of static friction of the car's tires from this data and then create a new table of different car speeds and minimum turning radii to not skid. • Attach a pendulum of known weight (say, 2 N) to a force sensor and cause the bob to swing in a 180-degree arc. Ask students, "At the bottom, the bob is neither speeding up nor slowing down, so what force is registered at the bottom?" Expect students to (incorrectly) answer, "2 N."	
Teacher Resources	*Teacher Note*
• Lab equipment, computers, analysis programs, projectors	

**Differentiating Instruction:
Students with Disabilities, English Language Learners,
and Gifted & Talented Students**

Examples of Strategies and Practices that Support Students with Disabilities:
- Use of visual and multisensory formats
- Use of assisted technology
- Use of prompts
- Modification of content and student products
- Testing accommodations
- Authentic assessments

Examples of Strategies and Practices that Support Gifted & Talented Students:
- Adjusting the pace of lessons
- Curriculum compacting
- Inquiry-based instruction
- Independent study
- Higher-order thinking skills
- Interest-based content
- Student-driven instruction
- Real-world problems and scenarios

Examples of Strategies and Practices that Support English Language Learners:
- Pre-teaching of vocabulary and concepts

- Visual learning, including graphic organizers
- Use of cognates to increase comprehension
- Teacher modeling
- Pairing students with beginning English language skills with students who have more advanced English language skills
- Scaffolding
- Word walls
- Sentence frames
- Think-pair-share
- Cooperative learning groups

Advanced Placement Physics Grade 12 Framework

Unit Title: Momentum	
Unit Summary: Unit 5 introduces students to the relationship between force, time, and momentum via calculations, data analysis, designing experiments, and making predictions. Students will learn how to use new models and representations to illustrate the law of the conservation of momentum of objects and systems while simultaneously building on their knowledge of previously studied representations. Using the law of the conservation of momentum to analyze physical situations gives students a more complete picture of forces and leads them to revisit their misconceptions surrounding Newton's third law. Students will also have the opportunity to make connections between the conserved quantities of momentum and energy to determine under what conditions each quantity is conserved. It's essential that students are not only comfortable solving numerical equations (such as the speed of a system after an inelastic collision) but also confident in their ability to discuss when momentum is conserved and how the type of collision affects the outcome. Threading such connections between physical quantities is fundamental to understanding the broader relationship between this unit and the rest of the course. Students will have more opportunities to apply conservation laws to make predictions and justify claims in Unit 7 when they are introduced to rotational quantities.	
Primary Interdisciplinary Connections: MP.2, MP.4, HSN-Q.A.1, HSN-Q.A.2, HSN-Q.A.3	
21st Century Career and Life Themes: Creativity and Innovation, Critical Thinking and Problem Solving, Communication and Collaboration, Information Literacy, Media Literacy	
Learning Targets	
NJSLS Standards: HS-PS3-1, HS-PS3-2, HS-PS3-3, HS-PS3-4, HS-PS3-6	
Technology Standards: 8.1.12.A.1, 8.1.12.A.2, 8.1.12.A.3, 8.1.12.A.4, 8.1.12.A.5, 8.1.P.B.1, 8.1.2.B.1, 8.1.5.B.1, 8.1.8.B.1, 8.1.2.C.1, 8.1.12.C.1, 8.1.12.D.5, 8.1.12.E.1, 8.1.12.F.1, 8.2.12.A.1, 8.2.12.C.3, 8.2.12.C.4, 8.2.12.C.5, 8.2.12.E.1	
ELA Companion Standards: RST.11-12.1, WHST.9-12.7, WHST.11-12.8, WHST.9-12.9, SL.11-12.5	
Content Statements:	
1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
2	Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).
3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*
4	Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of

	thermodynamics).
5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Big Idea: The interactions of an object with other objects can be described by forces. Interactions between systems can result in changes in those systems. Changes that occur as a result of interactions are constrained by conservation laws.

Unit Essential Questions:	**Unit Enduring Understandings:**
• How does pushing an object change its momentum? • How do interactions with other objects or systems change the linear momentum of a system? • How is the physics definition of momentum different from how momentum is used? • to describe things in everyday life? • How does the law of the conservation of momentum govern interactions between objects or systems? • How can momentum be used to determine fault in car crashes?	• A force exerted on an object can change the momentum of the object. • Interactions with other objects or systems can change the total linear momentum of a system. • Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems. • The linear momentum of a system is conserved.

Unit Learning Targets

Students will…

- 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.
- 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.
- 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.
- 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 collision.
- Design a plan for collecting data to investigate the relationship between changes in momentum and the average force.
- 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.).

- 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.
- 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.
- Perform an analysis on data presented as a force-time graph and predict the outcome
- Define open and closed systems for everyday situations and apply conservation concepts for energy change and linear motion.
- Make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions.
- 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 qualitatively in two-dimensional situations.
- 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.
- 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.
- 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.
- 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.
- 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.
- Apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy.
- Analyze data that verify conservation of momentum in collisions with and without an external frictional force.
- Classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values.

Evidence of Learning
Summative Assessment: Labs, Unit Tests, Benchmarks
Formative Assessments: • Quizzes • Section Tests • Take home assignments

Lesson Plans	
Activities/Interdisciplinary Connections	*Timeframe*
• Ask students to imagine a pitcher throwing a baseball and a catcher catching it. Students will debate who exerted more force on the ball (no way to know), who applied greater impulse (same for both), and who did a greater magnitude of net work on the ball (same). Repeat for a pitcher throwing the baseball and a batter hitting it back at the same speed. • Connect a spring-loaded lanyard between a cart and force sensor, with a motion sensor on the other side of the cart. Have students take force and motion versus time data as the lanyard contracts and pulls, accelerating the cart. Show that impulse applied to the cart equals the cart's change in momentum. • Have students use momentum bar charts to explain why a dart bouncing off a cart makes the cart move faster than if the dart sticks to the cart, passes through the cart, or stops and drops after colliding with the cart. • Have a cart crash into a force sensor set to its highest setting in three different ways: cart sticks to sensor, cart bounces off the sensor on its hard side, and cart bounces off the sensor with its spring side. Have students predict in which case more force is registered, and explain why after each experiment is done. • Have two carts with different masses collide in a non-stick collision. Film the carts with a phone camera from above, with a meterstick next to the track. Have students use a frame-by-frame review app to determine the cart's	4 weeks

initial/final speeds, whether momentum was conserved, and whether the collision was elastic.	
Teacher Resources	*Teacher Note*
• Lab equipment, computers, analysis programs, projectors	

Differentiating Instruction: Students with Disabilities, English Language Learners, and Gifted & Talented Students

Examples of Strategies and Practices that Support Students with Disabilities:
- Use of visual and multisensory formats
- Use of assisted technology
- Use of prompts
- Modification of content and student products
- Testing accommodations
- Authentic assessments

Examples of Strategies and Practices that Support Gifted & Talented Students:
- Adjusting the pace of lessons
- Curriculum compacting
- Inquiry-based instruction
- Independent study
- Higher-order thinking skills
- Interest-based content
- Student-driven instruction
- Real-world problems and scenarios

Examples of Strategies and Practices that Support English Language Learners:
- Pre-teaching of vocabulary and concepts
- Visual learning, including graphic organizers
- Use of cognates to increase comprehension
- Teacher modeling
- Pairing students with beginning English language skills with students who have more advanced English language skills
- Scaffolding
- Word walls
- Sentence frames
- Think-pair-share
- Cooperative learning groups

Advanced Placement Physics Grade 12 Framework

Unit Title: Energy	
Unit Summary: In Unit 4, students will be introduced to the idea of conservation as a foundational model of physics, along with the concept of work as the agent of change for energy. As in earlier units, students will once again utilize both familiar and new models and representations to analyze physical situations, now with force or energy as major components. Students will be encouraged to call upon their knowledge of Units 1–4 to determine the most appropriate technique and will be challenged to understand the limiting factors of each. Describing, creating, and using these representations will also help students grapple with common misconceptions that they may have about energy, such as whether or not a single object can "have" potential energy. A thorough understanding of these energy models will support students' ability to make predications—and ultimately justify claims with evidence—about physical situations. This is crucial, as the mathematical models and representations used in Unit 4 will mature throughout the course and appear in subsequent units. As students' comprehension of energy (particularly kinetic, potential, and microscopic internal energy) evolves, they will begin to connect and relate knowledge across scales, concepts, and representations, as well as across disciplines, particularly physics, chemistry, and biology.	
Primary Interdisciplinary Connections: MP.2, MP.4, HSN-Q.A.1, HSN-Q.A.2, HSN-Q.A.3	
21st Century Career and Life Themes: Creativity and Innovation, Critical Thinking and Problem Solving, Communication and Collaboration, Information Literacy, Media Literacy	
Learning Targets	
NJSLS Standards: HS-PS3-1, HS-PS3-2, HS-PS3-3, HS-PS3-4, HS-PS3-6	
Technology Standards: 8.1.12.A.1, 8.1.12.A.2, 8.1.12.A.3, 8.1.12.A.4, 8.1.12.A.5, 8.1.P.B.1, 8.1.2.B.1, 8.1.5.B.1, 8.1.8.B.1, 8.1.2.C.1, 8.1.12.C.1, 8.1.12.D.5, 8.1.12.E.1, 8.1.12.F.1, 8.2.12.A.1, 8.2.12.C.3, 8.2.12.C.4, 8.2.12.C.5, 8.2.12.E.1	
ELA Companion Standards: RST.11-12.1, WHST.9-12.7, WHST.11-12.8, WHST.9-12.9, SL.11-12.5	
Content Statements:	
1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
2	Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).
3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*
4	Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).
5	Develop and use a model of two objects interacting through electric or magnetic fields to

	illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Big Idea: The interactions of an object with other objects can be described by forces. Interactions between systems can result in changes in those systems. Changes that occur as a result of interactions are constrained by conservation laws.

Unit Essential Questions:

- How does pushing something give it energy?
- How is energy exchanged and transformed within or between systems?
- How does the choice of system influence how energy is stored or how work is done?
- How does energy conservation allow the riders in the back car of a rollercoaster to have a thrilling ride?
- How can the idea of potential energy be used to describe the work done to move celestial bodies?
- How is energy transferred between objects or systems?
- How does the law of conservation of energy govern the interactions between objects and systems?

Unit Enduring Understandings:

- Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.
- A force exerted on an object can change the kinetic energy of the object.
- Interactions with other objects or systems can change the total energy of a system.
- The energy of a system is conserved.

Unit Learning Targets

Students will…

- Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.
- 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.
- Use net force and velocity vectors to determine qualitatively whether the kinetic energy of an object would increase, decrease, or remain unchanged.
- Use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether the kinetic energy of that object would increase, decrease, or remain unchanged.
- Apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object.

- 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.
- Predict changes in the total energy of the system due to changes in position and speed of objects or frictional interactions within the system.
- 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.
- 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.
- Create 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.
- 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.
- Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy.
- Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system.
- 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.
- Describe and make predictions about the internal energy of systems.
- Calculate changes in kinetic energy and potential energy of a system using information from representations of that system.
- Design an experiment and analyze data to determine how a force exerted on an object or system does work on the object or system as it moves through a distance.
- 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.
- 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.
- 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).
- 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).

Evidence of Learning

Summative Assessment: Labs, Unit Tests, Benchmarks	
Formative Assessments: • Quizzes • Section Tests • Take home assignments	

Lesson Plans

Activities/Interdisciplinary Connections	*Timeframe*
• Release a low-friction cart (mass *m*) from the top of a ramp, have students time (*t*) how long it takes to reach the bottom, and measure the release height *h* and track length *L*. Have students calculate velocity using $v = L/t$, and then calculate *mgh* and $½mv^2$. The two energies are different; explain what incorrect assumptions lead to the difference in energies. • First square: Describe an everyday situation (e.g., "a car goes downhill, speeding up even as the brakes are pressed") along with a diagram. Second square: Free-body diagram with an arrow off to the side representing the object's displacement. Third square: Energy bar charts (initial and final). Fourth square: For each force on the free-body diagram, state whether that force performs positive or negative work and what energy transformation that force is responsible for. • Give each group a spring-loaded ball launcher, scale, and meterstick. Ask them to determine the spring constant of the spring in the launcher. • Ask students to consider a cart that rolls from rest down a ramp and then around a vertical loop. For the cart to complete the loop without falling out, the cart must be released at a height higher than the top of the loop. Have students explain why this is the case using energy and circular motion principles. • Student A writes a conservation of energy equation (either symbolically or with numbers and units plugged in). Student B then	2 weeks

describes a situation that the equation could apply to, draws a diagram, and draws energy bar charts.	
Teacher Resources	*Teacher Note*
• Lab equipment, computers, analysis programs, projectors	

Differentiating Instruction: Students with Disabilities, English Language Learners, and Gifted & Talented Students

Examples of Strategies and Practices that Support Students with Disabilities:
• Use of visual and multisensory formats
• Use of assisted technology
• Use of prompts
• Modification of content and student products
• Testing accommodations
• Authentic assessments

Examples of Strategies and Practices that Support Gifted & Talented Students:
• Adjusting the pace of lessons
• Curriculum compacting
• Inquiry-based instruction
• Independent study
• Higher-order thinking skills
• Interest-based content
• Student-driven instruction
• Real-world problems and scenarios

Examples of Strategies and Practices that Support English Language Learners:
• Pre-teaching of vocabulary and concepts
• Visual learning, including graphic organizers
• Use of cognates to increase comprehension
• Teacher modeling
• Pairing students with beginning English language skills with students who have more advanced English language skills
• Scaffolding
•Word walls
•Sentence frames
•Think-pair-share
•Cooperative learning groups

Advanced Placement Physics Grade 12 Framework

Unit Title: Simple Harmonic Motion	
Unit Summary: In Unit 6, students will continue to use the same tools, techniques, and models that they have been using throughout this course. However, they will now use them to analyze a new type of motion: simple harmonic motion. Although simple harmonic motion is unique, students will learn that even in new situations, the fundamental laws of physics remain the same. Energy bar charts, as well as free-body diagrams, become increasingly important as students work toward determining which model is most appropriate for a given physical situation. Preconceptions—such as the relationship between the amplitude and period of oscillation—will also be addressed to provide students with a more nuanced awareness of simple harmonic motion. Students are expected to use the content knowledge they gained in the first five units to make and defend claims while also making connections in and across the content topics and big ideas. Because Unit 6 is the first unit in which students possess all the tools of force, energy, and momentum conservation, it's important that teachers scaffold lessons to help them develop a better understanding of each fundamental physics principles as well as its limitations. Throughout this unit, students will be asked to create force, energy, momentum, and position versus time graphs for a single scenario and to make predictions based on their representations. Students will enhance their study of motion when they learn about oscillatory motion in Unit 10.	
Primary Interdisciplinary Connections: MP.2, MP.4, HSN-Q.A.1, HSN-Q.A.2, HSN-Q.A.3	
21st Century Career and Life Themes: Creativity and Innovation, Critical Thinking and Problem Solving, Communication and Collaboration, Information Literacy, Media Literacy	
Learning Targets	
NJSLS Standards: HS-PS3-1, HS-PS3-2, HS-PS3-3, HS-PS3-4, HS-PS3-6	
Technology Standards: 8.1.12.A.1, 8.1.12.A.2, 8.1.12.A.3, 8.1.12.A.4, 8.1.12.A.5, 8.1.P.B.1, 8.1.2.B.1, 8.1.5.B.1, 8.1.8.B.1, 8.1.2.C.1, 8.1.12.C.1, 8.1.12.D.5, 8.1.12.E.1, 8.1.12.F.1, 8.2.12.A.1, 8.2.12.C.3, 8.2.12.C.4, 8.2.12.C.5, 8.2.12.E.1	
ELA Companion Standards: RST.11-12.1, WHST.9-12.7, WHST.11-12.8, WHST.9-12.9, SL.11-12.5	
Content Statements:	
1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
2	Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).
3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*
4	Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results

	in a more uniform energy distribution among the components in the system (second law of thermodynamics).
5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Big Idea: The interactions of an object with other objects can be described by forces. Changes that occur as a result of interactions are constrained by conservation laws.

Unit Essential Questions:	**Unit Enduring Understandings:**
• How does a restoring force differ from a "regular" force? • How does the presence of restoring forces predict and lead to harmonic motion? • How does a spring cause an object to oscillate? • How can oscillations be used to make our lives easier? • How does the law of conservation of energy govern the interactions between objects and systems? • How can energy stored in a spring be used to create motion?	• Classically, the acceleration of an object interacting with other objects can be predicted by using a=F/m. • The energy of a system is conserved.

Unit Learning Targets

Students will…

- Predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties.
- 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.
- Analyze data to identify qualitative and 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 and use those data to determine the value of an unknown.
- Construct a qualitative and/ or quantitative explanation of oscillatory behavior given evidence of a restoring force.
- 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.

- Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy.
- Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system.
- 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.
- Describe and make predictions about the internal energy of systems.
- Calculate changes in kinetic energy and potential energy of a system using information from representations of that system.

Evidence of Learning

Summative Assessment: Labs, Unit Tests, Benchmarks

Formative Assessments:
- Quizzes
- Section Tests
- Take home assignments

Lesson Plans

Activities/Interdisciplinary Connections	*Timeframe*
• Have students determine the spring constant of a spring using (1) known masses and meterstick only and then (2) known masses and stopwatch only. • Have students use a pendulum to measure the acceleration of gravity. Ask them to refine the experiment from single-trial calculation, to taking an average, to making a graph of linearized data. • Make a pendulum bob oscillate with the other end of the string "clamped" between your fingers. While the bob oscillates, pull the string through your fingers so that the string length is shortened. Before doing this, ask students what will happen to the period of the oscillation and the amplitude (measured in degrees), and then explain why the period decreases and the amplitude angle increases. • A cart wiggles on a horizontal spring. A blob of clay is dropped on the cart and sticks (could be when the cart is at the center or at one end). Ask	2 weeks

students to explain what happened to the period, total energy, amplitude of motion, and maximum speed? • Students choose a song and find its tempo (beats per minute). Students then must build a pendulum so that it swings back and forth on each beat. Students are then given a spring. They must find the spring's constant and then find the amount of mass necessary to make the spring-mass oscillate on each beat.	
Teacher Resources	*Teacher Note*
• Lab equipment, computers, analysis programs, projectors	

Differentiating Instruction: Students with Disabilities, English Language Learners, and Gifted & Talented Students

Examples of Strategies and Practices that Support Students with Disabilities:

- Use of visual and multisensory formats
- Use of assisted technology
- Use of prompts
- Modification of content and student products
- Testing accommodations
- Authentic assessments

Examples of Strategies and Practices that Support Gifted & Talented Students:

- Adjusting the pace of lessons
- Curriculum compacting
- Inquiry-based instruction
- Independent study
- Higher-order thinking skills
- Interest-based content
- Student-driven instruction
- Real-world problems and scenarios

Examples of Strategies and Practices that Support English Language Learners:

- Pre-teaching of vocabulary and concepts
- Visual learning, including graphic organizers
- Use of cognates to increase comprehension
- Teacher modeling
- Pairing students with beginning English language skills with students who have more advanced English language skills
- Scaffolding

- Word walls
- Sentence frames
- Think-pair-share
- Cooperative learning groups

Advanced Placement Physics Grade 12 Framework

Unit Title: Torque and Rotational Motion	
Unit Summary: Unit 7 completes the study of mechanical physics by introducing students to torque and rotational motion. Although these topics present more complex scenarios, the tools of analysis remain the same: The content and models explored in the first six units of AP Physics 1 set the foundation for Unit 7. During their study of torque and rotational motion, students will be confronted with different ways of thinking about and modeling forces. As in previous units, it’s critical that students are given opportunities to create and use representations and models to make predictions and justify claims. It’s equally important that students are comfortable deriving new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. Unit 7 also focuses on the mathematical practice of estimating quantities that can describe natural phenomena. For example, students need to be able to estimate the torque on an object caused by various forces in comparison to other situations. Although this particular science practice doesn’t appear often in AP Physics 1, it nonetheless is an important conceptual skill for students to be able to compare estimated values of physical quantities. Throughout this unit, students will have opportunities to compare and connect their understanding of linear and rotational motion, dynamics, energy, and momentum to make meaning of these concepts as a whole, rather than as distinct and separate units.	
Primary Interdisciplinary Connections: MP.2, MP.4, HSN-Q.A.1, HSN-Q.A.2, HSN-Q.A.3	
21st Century Career and Life Themes: Creativity and Innovation, Critical Thinking and Problem Solving, Communication and Collaboration, Information Literacy, Media Literacy	
Learning Targets	
NJSLS Standards: HS-PS3-1, HS-PS3-2, HS-PS3-3, HS-PS3-4, HS-PS3-6	
Technology Standards: 8.1.12.A.1, 8.1.12.A.2, 8.1.12.A.3, 8.1.12.A.4, 8.1.12.A.5, 8.1.P.B.1, 8.1.2.B.1, 8.1.5.B.1, 8.1.8.B.1, 8.1.2.C.1, 8.1.12.C.1, 8.1.12.D.5, 8.1.12.E.1, 8.1.12.F.1, 8.2.12.A.1, 8.2.12.C.3, 8.2.12.C.4, 8.2.12.C.5, 8.2.12.E.1	
ELA Companion Standards: RST.11-12.1, WHST.9-12.7, WHST.11-12.8, WHST.9-12.9, SL.11-12.5	
Content Statements:	
1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
2	Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).
3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*
4	Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results

	in a more uniform energy distribution among the components in the system (second law of thermodynamics).
5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Big Idea: The interactions of an object with other objects can be described by forces. Interactions between systems can result in changes in those systems. Changes that occur as a result of interactions are constrained by conservation laws.

Unit Essential Questions:	**Unit Enduring Understandings:**
• How does a system at rotational equilibrium compare to a system in translational equilibrium? • How does the choice of system and rotation point affect the forces that can cause a torque on an object or a system? • How can balanced forces cause rotation? • Why does it matter where the door handle is placed? • Why are long wrenches more effective? • How can an external net torque change the angular momentum of a system? • Why is a rotating bicycle wheel more stable than a stationary one? • How does the conservation of angular momentum govern interactions between objects and systems? • Why do planets move faster when they travel closer to the sun?	• All forces share certain common characteristics when considered by observers in inertial reference frames. • A force exerted on an object can cause a torque on that object. • A net torque exerted on a system by other objects or systems will change the angular momentum of the system. • The angular momentum of a system is conserved.

Unit Learning Targets

Students will…

- Express the motion of an object using narrative, mathematical, and graphical representations.
- Express the motion of an object using narrative, mathematical, and apply to constant acceleration situations.
- Compare the torques on an object caused by various forces.
- Estimate the torque on an object caused by various forces in comparison with other

situations.

- Design an experiment and analyze data testing a question about torques in a balanced rigid system.
- Calculate torques on a two-dimensional system in static equilibrium by examining a representation or model (such as a diagram or physical construction).
- Use representations of the relationship between force and torque.
- 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.
- Plan data-collection and analysis strategies designed to test the relationship between a torque exerted on an object.
- 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.
- 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.
- 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.
- 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.
- 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.
- 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.
- 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.
- Use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular momentum.
- 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.
- The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted.
- Make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque.
- Make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero.

- 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.

Evidence of Learning

Summative Assessment: Labs, Unit Tests, Benchmarks

Formative Assessments:

- Quizzes
- Section Tests
- Take home assignments

Lesson Plans

Activities/Interdisciplinary Connections	*Timeframe*
• Spin a bike wheel (preferably with the tire removed so that it will roll on its metal rims), and release it from rest on a floor or long table. Have students predict what will happen to the wheel's linear velocity (will increase) and its angular velocity (will decrease) as the wheel "peels out." Then explain why this happens using a force diagram. • Have students release a yo-yo from rest, calculate its acceleration from distance and time measurements, and then determine the yo-yo's rotational inertia (requires the yo-yo's mass and the radius at which the string connects to the yo-yo). Next, have them roll the yo-yo down a ramp and use distance and time data to construct a conservation of energy equation that can be solved for the yo-yo's rotational inertia. • Obtain a ring and a disk of equal mass and radius, and load up a low-friction cart with weights to make it the same mass. "Race" the three objects from rest down identical inclines to show students the cart wins, then the disk, and then the ring. Have students explain why, with forces and then with energy. • A wheel rolls down an incline from rest and across a flat surface. Case 1: Tracks are rough	4 weeks

enough that there is no slipping. Case 2: Tracks have some friction, but there is slipping. Case 3: Tracks have negligible friction. Have students rank translational kinetic energies at the end, rotational kinetic energies at the end, and total mechanical energies of the wheel at the end as three separate tasks. ($K_{T3} > K_{T2} > K_{T1}$), ($K_{R1} > K_{R2} > K_{R3}$), and ($E_1 = E_3 > E_2$).	
Teacher Resources	*Teacher Note*
• Lab equipment, computers, analysis programs, projectors	

Differentiating Instruction: Students with Disabilities, English Language Learners, and Gifted & Talented Students

Examples of Strategies and Practices that Support Students with Disabilities:
• Use of visual and multisensory formats
• Use of assisted technology
• Use of prompts
• Modification of content and student products
• Testing accommodations
• Authentic assessments

Examples of Strategies and Practices that Support Gifted & Talented Students:
• Adjusting the pace of lessons
• Curriculum compacting
• Inquiry-based instruction
• Independent study
• Higher-order thinking skills
• Interest-based content
• Student-driven instruction
• Real-world problems and scenarios

Examples of Strategies and Practices that Support English Language Learners:
• Pre-teaching of vocabulary and concepts
• Visual learning, including graphic organizers
• Use of cognates to increase comprehension
• Teacher modeling
• Pairing students with beginning English language skills with students who have more advanced English language skills
• Scaffolding
•Word walls

- Sentence frames
- Think-pair-share
- Cooperative learning groups

Advanced Placement Physics Grade 12 Framework

Unit Title: Electrical Charge and Electrical Force	
Unit Summary: Although Unit 8 presents students with physical phenomena that are difficult or impossible to directly observe, the concepts of electric charge and electric force are the cornerstones of the study of electricity and magnetism. As in earlier units, the foundation of this unit includes the study of relationships and change: Students are expected to be able to discuss what happens to force when there is a change in the separation between charges or the magnitude of charges. It's essential for students to be able to use mathematics and mathematical relationships as evidence for claims, to analyze someone else's mathematical derivation, and/or to explain their own mathematical derivation in a narrative. Throughout this unit, students will also apply and make predictions about conserved quantities, which will be further developed and applied in Unit 9. Helping students practice the skill of constructing scientific explanations of phenomena based on scientific practices should also be a focus of Unit 8, as it helps students readily make comprehensive predictions about new phenomena. Students will also use familiar representations and models to make predictions and justify claims. These will help students dispel some of the common misconceptions that they may continue to have about forces, such as two charged objects with different net charges applying different magnitude forces on the other object. The content and ideas presented in Unit 8 set a solid foundation for students to be able to investigate and understand both DC circuits, in Unit 9, and the topics of electricity and magnetism, in AP Physics 2.	
Primary Interdisciplinary Connections: MP.2, MP.4, HSN-Q.A.1, HSN-Q.A.2, HSN-Q.A.3	
21st Century Career and Life Themes: Creativity and Innovation, Critical Thinking and Problem Solving, Communication and Collaboration, Information Literacy, Media Literacy	
Learning Targets	
NJSLS Standards: HS-PS3-1, HS-PS3-2, HS-PS3-3, HS-PS3-4, HS-PS3-6	
Technology Standards: 8.1.12.A.1, 8.1.12.A.2, 8.1.12.A.3, 8.1.12.A.4, 8.1.12.A.5, 8.1.P.B.1, 8.1.2.B.1, 8.1.5.B.1, 8.1.8.B.1, 8.1.2.C.1, 8.1.12.C.1, 8.1.12.D.5, 8.1.12.E.1, 8.1.12.F.1, 8.2.12.A.1, 8.2.12.C.3, 8.2.12.C.4, 8.2.12.C.5, 8.2.12.E.1	
ELA Companion Standards: RST.11-12.1, WHST.9-12.7, WHST.11-12.8, WHST.9-12.9, SL.11-12.5	
Content Statements:	
1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
2	Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).
3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

4	Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).
5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Big Idea: Objects and systems have properties such as mass and charge. Systems may have internal structure. The interactions of an object with other objects can be described by forces. Changes that occur as a result of interactions are constrained by conservation laws.

Unit Essential Questions:

- How does electric charge change the way that something interacts with its surroundings?
- How do you decide what to believe about scientific claims?
- How does something we cannot see determine how an object behaves?
- How do charges exert forces on each other?
- How does the conservation of charge help us understand how charged objects behave?
- Why can you stick a balloon on the ceiling, if rubber is an insulator?

Unit Enduring Understandings:

- Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.
- Electric charge is a property of an object or a system that affects its interactions with other objects or systems containing charge.
- At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

Unit Learning Targets

Students will…

- Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.
- Make claims about natural phenomena based on conservation of electric charge
- 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.
- Construct an explanation of the two-charge model of electric charge.
- Use Coulomb’s Law qualitatively and quantitatively to make predictions about interactions between collections of electric point charges.
- Connect the concepts of gravitational force and electric force to compare similarities and

differences between forces.

Evidence of Learning

Summative Assessment: Labs, Unit Tests, Benchmarks

Formative Assessments:
- Quizzes
- Section Tests
- Take home assignments

Lesson Plans

Activities/Interdisciplinary Connections	*Timeframe*
• Charge two identical balloons connected to the ceiling by 1 to 2 m long strings. (It may need to be rubbed against a Van de Graaf generator.) As they repel each other and cause their strings to angle, have students make the necessary measurements to be able to calculate the charge on each balloon (assuming they have the same charge). • Object 1 is fixed in place, and object 2 is free to move; both are charged. Have students explain how the velocity and acceleration of object 2 are changing (increasing or decreasing) as object 2 moves toward (or away from) object 1 if both have the same (or different) sign and magnitude of charge. • Two charged balloons hang at equal heights from strings attached at the same point on the ceiling. However, balloon 1′s string makes a greater angle with the vertical. Student A thinks that balloon 2 has more charge than balloon 1, and Student B thinks that balloon 2 has more mass than balloon 1. Have students discuss the predictions and outline which parts of each argument are correct or incorrect. • Two identical spheres made of carbon-12 are in	4 weeks

space. An equal number of electrons are removed from both spheres so that the spheres remain at rest, with electric and gravitational forces balanced. Have students determine what fraction of the total electrons on each sphere were removed. (Answer: One out of every 5.56 • 10^{17} electrons was removed.) • Have students calculate the electric force repelling two protons in a helium nucleus (230.4 N if $r = 10^{-15}$ m), then predict whether it is gravity that holds the nucleus together. Next, have students calculate the gravitational force attracting the protons (1.86 • 10^{-34} N).	
Teacher Resources	*Teacher Note*
• Lab equipment, computers, analysis programs, projectors	

Differentiating Instruction:
Students with Disabilities, English Language Learners,
and Gifted & Talented Students

Examples of Strategies and Practices that Support Students with Disabilities:
• Use of visual and multisensory formats
• Use of assisted technology
• Use of prompts
• Modification of content and student products
• Testing accommodations
• Authentic assessments

Examples of Strategies and Practices that Support Gifted & Talented Students:
• Adjusting the pace of lessons
• Curriculum compacting
• Inquiry-based instruction
• Independent study
• Higher-order thinking skills
• Interest-based content
• Student-driven instruction
• Real-world problems and scenarios

Examples of Strategies and Practices that Support English Language Learners:
• Pre-teaching of vocabulary and concepts
• Visual learning, including graphic organizers

- Use of cognates to increase comprehension
- Teacher modeling
- Pairing students with beginning English language skills with students who have more advanced English language skills
- Scaffolding
- Word walls
- Sentence frames
- Think-pair-share
- Cooperative learning groups

Advanced Placement Physics Grade 12 Framework

Unit Title: DC Circuits	
Unit Summary: In Unit 9, students will draw on their knowledge of electricity and apply it to the conservation of charge in electric circuits. This unit will push students to move beyond mathematically solving for current, resistance, and voltage and will challenge them to make connections between system interactions and the changes that result from these interactions. For example, students must not only be able to calculate the resistance of a light bulb in a circuit; they must also be able to articulate the impact on other bulbs in the circuit if that light bulb is removed. Throughout the unit, it is essential that students have opportunities to create and use representations and models, especially as evidence to make predictions, justify claims, and overcome any preconceived notions about circuits. It is also important that students develop an understanding of the language used in Unit 8. Correctly using vocabulary terms such as “voltage,” “current,” and “energy” is essential to accurately describe, analyze, and reason with content presented in this course. By helping students relate theoretical models of electricity to real circuits, Unit 9 sets the stage for AP Physics C: Electricity and Magnetism, which explores circuits in greater depth.	
Primary Interdisciplinary Connections: MP.2, MP.4, HSN-Q.A.1, HSN-Q.A.2, HSN-Q.A.3	
21st Century Career and Life Themes: Creativity and Innovation, Critical Thinking and Problem Solving, Communication and Collaboration, Information Literacy, Media Literacy	
Learning Targets	
NJSLS Standards: HS-PS3-1, HS-PS3-2, HS-PS3-3, HS-PS3-4, HS-PS3-6	
Technology Standards: 8.1.12.A.1, 8.1.12.A.2, 8.1.12.A.3, 8.1.12.A.4, 8.1.12.A.5, 8.1.P.B.1, 8.1.2.B.1, 8.1.5.B.1, 8.1.8.B.1, 8.1.2.C.1, 8.1.12.C.1, 8.1.12.D.5, 8.1.12.E.1, 8.1.12.F.1, 8.2.12.A.1, 8.2.12.C.3, 8.2.12.C.4, 8.2.12.C.5, 8.2.12.E.1	
ELA Companion Standards: RST.11-12.1, WHST.9-12.7, WHST.11-12.8, WHST.9-12.9, SL.11-12.5	
Content Statements:	
1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
2	Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).
3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
4	Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Big Idea: Objects and systems have properties such as mass and charge. Systems may have internal structure. Changes that occur as a result of interactions are constrained by conservation laws.

Unit Essential Questions:	**Unit Enduring Understandings:**
• How do you decide what to believe about scientific claims? • How does something we cannot see determine how an object behaves? • How do the laws of conservation of charge and energy allow us to light our homes and businesses? • How does the conservation of charge govern interactions between objects and systems? • How does the law of conservation of energy govern the interactions between objects and systems?	• Electric charge is a property of an object or a system that affects its interactions with other objects or systems containing charge. • Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. • The energy of a system is conserved. • The electric charge of a system is conserved.

Unit Learning Targets

Students will…

- Make claims about natural phenomena based on conservation of electric charge.
- 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.
- Choose and justify the selection of data needed to determine resistivity for a given material.
- 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).
- Apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule ($\sum \Delta V = 0$) in a circuit with only a battery and resistors either in series or in, at most, one pair of parallel branches.
- 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.
- 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.

• 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. • Use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit.

Evidence of Learning
Summative Assessment: Labs, Unit Tests, Benchmarks
Formative Assessments: • Quizzes • Section Tests • Take home assignments

Lesson Plans	
Activities/Interdisciplinary Connections	*Timeframe*
• Ask students to imagine a wire immersed in water with both ends connected to a battery to short the wire and heat the water. Ask, "What heats the water faster: thick or thin wire? Long or short wire?" • Have students choose an object or a substance that somewhat conducts electricity but is not normally used in a circuit (e.g., cylinder of modeling dough, cup of water). Students determine whether this substance is ohmic using five batteries and a multimeter. • Student A draws a two- or three-resistor circuit with resistors labeled X, Y, and (maybe) Z. There are also a voltmeter and an ammeter in the circuit, correctly connected (voltmeter is connected in parallel to only one of the resistors). Student A says, "the voltmeter reading needs to increase" (or decrease) and "the ammeter reading needs to decrease" (or increase). It is up to Student B to determine which resistor needs to change (and how: increase or decrease) to make the meters both change in that way.	4 weeks

• Resistors R_S and r_S are in series with a battery, and R_P and r_P are in parallel with an identical battery, where $R_S = R_P > r_S = r_P$. Have students rank potential difference, current, and power dissipated for all four resistors. (Voltage: $R_P = r_P > R_S > r_S$, Current: $r_P > R_P > R_S = r_S$, Power: $r_P > R_P > R_S > r_S$).	
Teacher Resources	*Teacher Note*
• Lab equipment, computers, analysis programs, projectors	

Differentiating Instruction:
Students with Disabilities, English Language Learners, and Gifted & Talented Students

Examples of Strategies and Practices that Support Students with Disabilities:
- Use of visual and multisensory formats
- Use of assisted technology
- Use of prompts
- Modification of content and student products
- Testing accommodations
- Authentic assessments

Examples of Strategies and Practices that Support Gifted & Talented Students:
- Adjusting the pace of lessons
- Curriculum compacting
- Inquiry-based instruction
- Independent study
- Higher-order thinking skills
- Interest-based content
- Student-driven instruction
- Real-world problems and scenarios

Examples of Strategies and Practices that Support English Language Learners:
- Pre-teaching of vocabulary and concepts
- Visual learning, including graphic organizers
- Use of cognates to increase comprehension
- Teacher modeling
- Pairing students with beginning English language skills with students who have more advanced English language skills
- Scaffolding
- Word walls

- Sentence frames
- Think-pair-share
- Cooperative learning groups

Advanced Physics Physics Grade 12 Framework

Unit Title: Mechanical Waves and Sounds	
Unit Summary: In Unit 10, students will move away from the main themes of the previous units and learn about mechanical waves. Although concepts like oscillation, energy, and motion carry over into the study of waves, students will be introduced to new tools to communicate scientific phenomena and solve scientific models. Standing wave models, for example, are applied in Unit 10 to support a more in-depth knowledge of musical instruments and sounds. Because knowledge of mechanical waves is essential for understanding a wide range of physical phenomena (including light and the wave properties of matter), students will have several opportunities in Unit 10 to connect and relate knowledge across various scales, concepts, and representations. Being able to identify and describe the relationships between physical quantities and use these relationships as justification for claims are equally essential. Although its content remains distinct from earlier units, Unit 10 presents concepts that will help students succeed in later physics courses. Students who take AP Physics 2 will further investigate the ideas presented in Unit 10 through their additional study of mechanical waves.	
Primary Interdisciplinary Connections: MP.2, MP.4, HSA-SSE.A.1, HSA-SSE.B.3, HSA.CED.A.4	
21st Century Career and Life Themes: Creativity and Innovation, Critical Thinking and Problem Solving, Communication and Collaboration, Information Literacy, Media Literacy	
Learning Targets	
NJSLS Standards: HS-PS4-1.	
Technology Standards: 8.1.12.A.1, 8.1.12.A.2, 8.1.12.A.3, 8.1.12.A.4, 8.1.12.A.5, 8.1.P.B.1, 8.1.2.B.1, 8.1.5.B.1, 8.1.8.B.1, 8.1.2.C.1, 8.1.12.C.1, 8.1.12.D.5, 8.1.12.E.1, 8.1.12.F.1, 8.2.12.A.1, 8.2.12.C.3, 8.2.12.C.4, 8.2.12.C.5, 8.2.12.E.1	
ELA Companion Standards: RST.11-12.7	
Content Statements:	
1	Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
Big Idea: Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.	
Unit Essential Questions: • How can data be used to help us create models of phenomena we see around us? • Why does a police siren sound different when it is moving	**Unit Enduring Understandings:** • A wave is a traveling disturbance that transfers energy and momentum. • A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy.

toward you than when it is moving away from you? • What happens when two waves meet? • How is resonance responsible for the Tacoma Narrows Bridge collapse? • How is sound produced?	• Interference and superposition lead to standing waves and beats.

Unit Learning Targets

Students will…

- 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.
- Describe representations of transverse and longitudinal waves.
- Describe sound in terms of transfer of energy and momentum in a medium and relate the concepts to everyday examples.
- Use graphical representation of a periodic mechanical wave to determine the amplitude of the wave.
- 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.
- 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.
- Use a visual representation of a periodic mechanical wave to determine the wavelength of the wave.
- Design an experiment to determine the relationship between periodic wave speed wavelength, and frequency and relate these concepts to everyday examples.
- Create or use a wave front diagram to demonstrate or interpret qualitatively the observed frequency of a wave, dependent on relative motions of source and observer.
- Use representations of individual pulses and construct representations to model the interaction of two wave pulses to analyze the superposition of two pulses.
- Design a suitable experiment and analyze data illustrating the superposition of mechanical waves (only for wave pulses or standing waves).
- 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.
- 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.
- 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.

- 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.
- Plan data-collection strategies, predict the outcome based on the relationship under test, perform data analysis, evaluate evidence compared with 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.
- Describe representations and models of situations in which standing waves result from the addition of incident and reflected waves confined to a region.
- 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.
- 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.
- Use a visual representation to explain how waves of slightly different frequency give rise to the phenomenon of beats.

Evidence of Learning

Summative Assessment: Labs, Unit Tests, Benchmarks

Formative Assessments:
- Quizzes
- Section Tests
- Take home assignments

Lesson Plans

Activities/Interdisciplinary Connections	*Timeframe*
• Have students use long springs to create a standing wave. The students make measurements necessary to find the wave speed (wavelength and period data) and the maximum speed attained at an antinode point (amplitude and period data). Students then calculate the wave speed and maximum “particle speed” and see that they are different. • Student A chooses one quantity (frequency, wavelength, wave speed) that stays constant, and a second that either increases or decreases. Student B must state what the third quantity does (increase or decrease) and then describe a situation where a wave undergoes the changes	4 weeks

that A prescribed. • Students are given several glass bottles. The students choose a song, research its sheet music, fill the bottles with amounts of water calculated to cause the bottles to resonate at the different tones of the song, and then play the song with the bottles. • Have students blow perpendicularly across a straw while a tone-detecting app on a smartphone is listening. The app registers the fundamental frequency of the standing wave in the straw; students use this and the straw length to calculate the speed of sound. Cut off lengths of straw and repeat, linearizing frequency and wavelength to get the speed of sound. • A pipe 2 m long is in a room where the speed of sound in the air is 343 m/s. Square 1: Students draw the first three harmonics if the pipe is open and calculate the harmonic frequencies. Square 2: Students draw the first three harmonics if the pipe is closed and calculate the frequencies. Square 3: Students plot on a number line the first three open frequencies and the first three closed frequencies with different symbols. Square 4: Students describe the pattern on the number line.	
Teacher Resources	*Teacher Note*
• Lab equipment, computers, analysis programs, projectors	

Differentiating Instruction: Students with Disabilities, English Language Learners, and Gifted & Talented Students

Examples of Strategies and Practices that Support Students with Disabilities:

- Use of visual and multisensory formats
- Use of assisted technology
- Use of prompts
- Modification of content and student products

• Testing accommodations
• Authentic assessments

Examples of Strategies and Practices that Support Gifted & Talented Students:
• Adjusting the pace of lessons
• Curriculum compacting
• Inquiry-based instruction
• Independent study
• Higher-order thinking skills
• Interest-based content
• Student-driven instruction
• Real-world problems and scenarios

Examples of Strategies and Practices that Support English Language Learners:
• Pre-teaching of vocabulary and concepts
• Visual learning, including graphic organizers
• Use of cognates to increase comprehension
• Teacher modeling
• Pairing students with beginning English language skills with students who have more advanced English language skills
• Scaffolding
•Word walls
•Sentence frames
•Think-pair-share
•Cooperative learning groups