Course Name: AP Physics

Team Names: Jon Collins

1st 9 weeks	Objectives	Vocabulary
1. NEWTONIAN MECHANICS and lab skills: Kinematics (including vectors, vector algebra, components of vectors, coordinate systems, displacement, velocity, and acceleration) Motion in one dimension: 3.A.1 An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. a. Displacement, velocity, and acceleration are all vector quantities. b. Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values. c. A choice of reference frame determines the direction and the magnitude of each of these quantities. 3.A.1.1 The student is able to express the motion of an object using narrative, mathematical, and graphical representations. 3.A.1.2 The student is able to design an experimental investigation of the motion of an object. 3.A.1.3 The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative, mathematical, and graphical representations. 4.A.1 The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. 4.A.1.1 The student is able to use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semiquantitatively. 4.A.2 The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time. a. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system. b. Force and acceleration are both vectors, with acceleration in the same direction as the net force. 4.A.2.1 The student is able to 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. c. Students will collect data, graph data using a best fit line, and obtain a formula from the graph. **The student can use mathematics appropriately.** 2.1 The student can justify the selection of a mathematical routine to solve problems. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 2.3 The student can estimate numerically quantities that describe natural phenomena. **The student can perform data analysis and evaluation of evidence.**		Velocity Acceleration Displacement

5.1 The student can analyze data to identify patterns or relationships. 5.2 The student can refine observations and measurements based on data analysis. 5.3 The student can evaluate the evidence provided by data sets in relation to a particular scientific question. **4 WEEKS**	
2. Newton's Laws and Forces (Forces and Newton's three laws of motion are integrated. Students also use vectors in two dimensions. 1.C.1 Inertial mass is the property of an object or a system that determines how its motion changes when it interacts with other objects or systems. 1.C.1.1 The student is able to design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration. 2.A.1 A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector. a. Vector fields are represented by field vectors indicating direction and magnitude. b. When more than one source object with mass or electric charge is present, the field value can be determined by vector addition. c. Conversely, a known vector field can be used to make inferences about the number, relative size, and location of sources. 2.B.1 A gravitational field g at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field. a. On the Earth, this gravitational force is called weight. b. The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force. c. If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically newtons/kilogram) at that location. 2.B.1.1 The student is able to apply F=mg to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems. 3.A.2 Forces are described by vectors a. Forces are detected by their influence on the motion of an object. b. Forces have magnitude and direction. 3.A.2.1 The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. 3.A.3 A force exerted on an object is always due to the interaction of that object with another object. a. An object cannot exert a force on itself. b. Even though an object is at rest, there may be forces exerted on that object by other objects. c. The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force	Force Free body diagram

exerted on the object by other objects.

3.A.3.1 The student is able to 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.

3.A.3.2 The student is able to challenge a claim that an object can exert a force on itself.

3.A.3.3 The student is able to describe a force as an interaction between two objects and identify both objects for any force.

3.A.3.4 The student is able to make claims about the force on an object due to the presence of other objects with the same property: mass, electric charge.

3.A.4 If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.

3.A.4.1 The student is able to construct explanations of physical situations involving the interaction of bodies using Newton’s third law and the representation of action-reaction pairs of forces.

3.A.4.2 The student is able to use Newton’s third law to make claims and predictions about the action-reaction pairs of forces when two objects interact.

3.A.4.3 The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton’s third law to identify forces.

3.B.1 If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.

3.B.1.1 The student is able to 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.

3.B.1.2 The student is able to 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.

3.B.1.3 The student is able to re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object.

3.B.2 Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.

a. An object can be drawn as if it was extracted from its environment and the interactions with the environment identified.

b. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force.

c. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free-body diagram to the algebraic representation.

3.B.2.1 The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively.

3.C.4 Contact forces result from the interaction of one object touching another object and they arise from interatomic electric forces. These forces include tension, friction, normal, and spring.

3.C.4.1 The student is able to make claims about various contact forces between objects based on the

microscopic cause of those forces (interatomic electric forces). 3.C.4.2 The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. 4.A.3 Forces that systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system. 4.A.3.1 The student is able to 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. 4.A.3.2 The student is able to 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. 5.A.3 An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system. 5.A.4. An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system. **4 WEEKS**	
3. Motion in two dimensions, including projectile motion a) Students should be able to add, subtract, and resolve displacement and velocity vectors, so they can: (1) Determine components of a vector along two specified, mutually perpendicular axes. (2) Determine the net displacement of a particle or the location of a particle relative to another. (3) Determine the change in velocity of a particle or the velocity of one particle relative to another. **1 WEEK**	

2nd 9 Weeks	Objectives	Vocabulary
4. Work, power, energy 3.E.1 The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the interval that the force is exerted. a. Only the component of the net force exerted on an object parallel or antiparallel to the displacement of the object will increase (parallel) or decrease (antiparallel) the kinetic energy of the object. b. The magnitude of the change in the kinetic energy is the product of the magnitude of the displacement and of the magnitude of the component of force parallel or antiparallel to the displacement. c. The component of the net force exerted on an object perpendicular to the direction of the displacement of the object can change the direction of the motion of the object without changing the kinetic energy of the object. This		Kinetic energy Potential energy Work Power

should include uniform circular motion and projectile motion.

4.C.1 The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples should include gravitational potential energy, elastic potential energy, and kinetic energy.

4.C.1.1 The student is able to 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.

4.C.1.2 The student is able to predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system.

4.C.2 Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the force is parallel to its displacement. The process through which the energy is transferred is called work.

a. If the force is constant during a given displacement, then the work done is the product of the displacement and the component of the force parallel or antiparallel to the displacement.

b. Work (change in energy) can be found from the area under a graph of the magnitude of the force component parallel to the displacement versus displacement.

4.C.2.1 The student is able to 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.

4.C.2.2 The student is able to 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.

5.A.1 A system is an object or collection of objects. The objects are treated as having no internal structure.

5.A.2 For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.

5.A.2.1 The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.

5.B.1 Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects.

5.B.1.1 The student is able to set up a representation or model showing that a single object can only have kinetic energy and use information about that object to calculate its kinetic energy.

5.B.1.2 The student is able to 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.

5.B.3 A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces.

a. The work done by a conservative force is independent of the path taken. The work description is used for forces external to the system. Potential energy is used when the forces are internal interactions between parts of the system.

b. Changes in the internal structure can result in changes in potential energy. Examples should include mass-

spring oscillators, objects falling in a gravitational field. c. The change in electric potential in a circuit is the change in potential energy per unit charge. 5.B.3.1 The student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. 5.B.3.2 The student is able to make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. 5.B.3.3 The student is able to 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. 5.B.4 The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system. a. Since energy is constant in a closed system, changes in a system's potential energy can result in changes to the system's kinetic energy. b. The changes in potential and kinetic energies in a system may be further 5.B.4.1 The student is able to describe and make predictions about the internal energy of systems. 5.B.4.2 The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. 5.B.5 Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. 5.B.5.1 The student is able to design an experiment and analyze data to examine how a force exerted on an object or system does work on the object or system as it moves through a distance. 5.B.5.2 The student is able to 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. 5.B.5.3 The student is able to 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. 5.B.5.4 The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). 5.B.5.5 The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. **3 WEEKS**	
5. Particles/linear Momentum 1.A.5: Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures. In AP Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an object.	Momentum Elastic collision In-elastic collision

1.A.5.1: The student is able to model verbally or visually the properties of a system based on its substructure and to relate this to changes in the system properties over time as external variables are changed.

3.D.1 The change in momentum of an object is a vector in the direction of the net force exerted on the object.

3.D.1.1 The student is able to 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.

3.D.2 The change in momentum of an object occurs over a time interval.

a. The force that one object exerts on a second object changes the momentum of the second object (in the absence of other forces on the second object).

b. The change in momentum of that object depends on the impulse, which is the product of the average force and the time interval during which the interaction occurred.

3.D.2.1 The student is able to 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.

3.D.2.2 The student is able to 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.

3.D.2.3 The student is able to analyze data to characterize the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted.

3.D.2.4 The student is able to design a plan for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time.

4.B.1 The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass.

4.B.1.1 The student is able to 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.).

4.B.1.2 The student is able to 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.

4.B.2 The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted.

a. The units for momentum are the same as the units of the area under the curve of a force versus time graph.

b. The changes in linear momentum and force are both vectors in the same direction.

4.B.2.1 The student is able to 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.

4.B.2.2 The student is able to perform analysis on data presented as a force-time graph and predict the change in momentum of a system.

5.A.2 For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.

5.A.2.1 The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.

5.D.1 In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.

a. In a closed system, the linear momentum is constant throughout the collision.

b. In a closed system, the kinetic energy after an elastic collision is the same as the kinetic energy before the collision.

5.D.1.1 The student is able to make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions.

5.D.1.2 The student is able to apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and only qualitatively in two-dimensional situations.

5.D.1.3 The student is able to 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.

5.D.1.4 The student is able to 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.

5.D.1.5 The student is able to 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.

5.D.2 In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.

a. In a closed system, the linear momentum is constant throughout the collision.

b. In a closed system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision.

5.D.2.1 The student is able to 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.

5.D.2.2 The student is able to 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.

5.D.2.3 The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy.

5.D.2.4 The student is able to analyze data that verify conservation of momentum in collisions with and without an external friction force.

5.D.2.5 The student is able to 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 finial velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values.

5.D.3 The velocity of the center of mass of the system cannot be changed by an interaction within the system.

a. The center of mass of a system depends upon the masses and positions of the objects in the system. In an isolated system (a system with no external forces), the velocity of the center of mass does not change.

b. When objects in a system collide, the velocity of the center of mass of the system will not change unless an external force is exerted on the system. (Note: Includes no calculations of centers of mass in Physics 1; however, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.) 5.D.3.1 The student is able to predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center of mass motion of the system and is able to determine that there is no external force). **2 WEEKS**	

6. Circular motion, Gravity, and Oscillations

Circular Motion

1. Uniform circular motion Students should understand the uniform circular motion of a particle, so they can:

a) Relate the radius of the circle and the speed or rate of revolution of the particle to the magnitude of the centripetal acceleration.

b) Describe the direction of the particle's velocity and acceleration at any instant during the Simple harmonic motion

c) Determine the components of the velocity and acceleration vectors at any instant, and sketch or identify graphs of these quantities.

d) Analyze situations in which an object moves with specified acceleration under the influence of one or more forces so they can determine the magnitude and direction of the net force, or of one of the forces that makes up the net force, in situations such as the following:

(1) Motion in a horizontal circle (e.g., mass on a rotating merry-go-round, or car rounding a banked curve). (2) Motion in a vertical circle (e.g., mass swinging on the end of a string, cart rolling down a curved track, rider on a Ferris wheel).

Gravity

1.C.2 Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields.

a. The gravitational mass of an object determines the amount of force exerted on the object by a gravitational field.

b. Near the Earth's surface, all objects fall (in a vacuum) with the same acceleration, regardless of their inertial mass.

1.C.3 Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.

1.C.3.1 The student is able to design a plan for collecting data to measure gravitational mass and inertial mass, and to distinguish between the two experiments.

2.B.2 The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object.

a. The gravitational field caused by a spherically symmetric object is a vector whose magnitude outside the object is equal to GM/r^2

b. Only spherically symmetric objects will be considered as sources of the gravitational field.

2.B.2.1 The student is able to apply $g=GM/r^2$ to calculate the gravitational field due to an object with mass M, where the field is a vector directed toward the center of the object of mass M.

2.B.2.2 The student is able to approximate a numerical value of the gravitational field (g) near the surface of an object from its radius and mass relative to those of the Earth or other reference objects.

3.C.1 Gravitational force describes the interaction of one object that has mass with another object that has mass.

a. The gravitational force is always attractive.

Simple harmonic motion
Centripetal force
Torque
Restoring Force
Equilibrium point

b. The magnitude of force between two spherically symmetric objects of mass m1 and m2 is Gm1m2/r^2 where r is the center-to-center distance between the objects. c. In a narrow range of heights above the Earth's surface, the local gravitational field, g, is approximately constant. 3.C.1.1 The student is able to use Newton's law of gravitation to calculate the gravitational force the two objects exert on each other and use that force in contexts other than orbital motion. 3.C.1.2 The student is able to use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving circular orbital motion. **<u>Oscillations</u>** 3.B.3 Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples should include gravitational force exerted by the Earth on a simple pendulum, mass-spring oscillator. a. For a spring that exerts a linear restoring force the period of a mass-spring oscillator increases with mass and decreases with spring stiffness. b. For a simple pendulum oscillating the period increases with the length of the pendulum. c. Minima, maxima, and zeros of position, velocity, and acceleration are features of harmonic motion. Students should be able to calculate force and acceleration for any given displacement for an object oscillating on a spring. 3.B.3.1 The student is able to predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. 3.B.3.2 The student is able to 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. 3.B.3.3 The student can analyze data to identify qualitative or quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion to use that data to determine the value of an unknown. 3.B.3.4 The student is able to construct a qualitative and/or a quantitative explanation of oscillatory behavior given evidence of a restoring force. 5.B.2 A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. 5.B.2.1 The student is able to 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. **3 WEEKS**	

3rd Nine weeks	Objectives	Vocabulary

7. Rotation

3.F.1 Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis.

a. The lever arm is the perpendicular distance from the axis of rotation or revolution to the line of application of the force.

b. The magnitude of the torque is the product of the magnitude of the lever arm and the magnitude of the force.

c. The net torque on a balanced system is zero.

3.F.1.1 The student is able to use representations of the relationship between force and torque.

3.F.1.2 The student is able to compare the torques on an object caused by various forces.

3.F.1.3 The student is able to estimate the torque on an object caused by various forces in comparison to other situations.

3.F.1.4 The student is able to design an experiment and analyze data testing a question about torques in a balanced rigid system.

3.F.1.5 The student is able to calculate torques on a two-dimensional system in static equilibrium, by examining a representation or model (such as a diagram or physical construction).

3.F.2 The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis.

a. Rotational motion can be described in terms of angular displacement, angular velocity, and angular acceleration about a fixed axis.

b. Rotational motion of a point can be related to linear motion of the point using the distance of the point from the axis of rotation.

c. The angular acceleration of an object or rigid system can be calculated from the net torque and the rotational inertia of the object or rigid system.

3.F.2.1 The student is able to 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.

3.F.2.2 The student is able to plan data collection and analysis strategies designed to test the relationship between a torque exerted on an object and the change in angular velocity of that object about an axis.

3.F.3 A torque exerted on an object can change the angular momentum of an object.

a. Angular momentum is a vector quantity, with its direction determined by a right-hand rule.

b. The magnitude of angular momentum of a point object about an axis can be calculated by multiplying the perpendicular distance from the axis of rotation to the line of motion by the magnitude of linear momentum.

c. The magnitude of angular momentum of an extended object can also be found by multiplying the rotational inertia by the angular velocity.

d. The change in angular momentum of an object is given by the product of the average torque and the time the torque is exerted. 3.F.3.1 The student is able to 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. 3.F.3.2 In an unfamiliar context or using representations beyond equations, the student is able to 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. 3.F.3.3 The student is able to 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. 4.D.1 Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as a positive or negative depending upon whether they give rise to or correspond to a counter clockwise or clockwise rotation with respect to an axis. 4.D.1.1 The student is able to 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. 4.D.1.2 The student is able to 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. 4.D.2 The angular momentum of a system may change due to interactions with other objects or systems. a. The angular momentum of a system with respect to an axis of rotation is the sum of the angular momenta, with respect to that axis, of the objects that make up the system. b. The angular momentum of an object about a fixed axis can be found by multiplying the momentum of the particle by the perpendicular distance from the axis to the line of motion of the object. c. Alternatively, the angular momentum of a system can be found from the product of the system's rotational inertia and its angular velocity. 4.D.2.1 The student is able to 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. 4.D.2.2 The student is able to 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. 4.D.3 The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted. 4.D.3.1 The student is able to 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. 4.D.3.2 The student is able to 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.	

5.A.2 For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings. 5.A.2.1 The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. 5.E.1 If the net external torque exerted on the system is zero, the angular momentum of the system does not change. 5.E.1.1 The student is able to make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque. 5.E.1.2 The student is able to make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero. 5.E.2 The angular momentum of a system is determined by the locations and velocities of the objects that make up the system. The rotational inertia of an object or system depends upon the distribution of mass within the object or system. Changes in the radius of a system or in the distribution of mass within the system result in changes in the system's rotational inertia, and hence in its angular velocity and linear speed for a given angular momentum. Note: Examples should include elliptical orbits in an Earth-satellite system. Mathematical expressions for the moments of inertia will be provided where needed. Students will not be expected to know the parallel axis theorem. 4.D.1 Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending upon whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis. 4.D.1.1 The student is able to 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. 4.D.1.2 The student is able to 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. **4 WEEKS**	
8. Waves 6.A.1 Waves can propagate via different oscillation modes such as transverse and longitudinal. a. Mechanical waves can be either transverse or longitudinal. Examples should include waves on a stretched string and sound waves. b. Electromagnetic waves are transverse waves. 6.A.1.1 The student is able to 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.	Wavelength Frequency Period Harmonic Beats Resonance Wave interference

6.A.1.2 The student is able to describe representations of transverse and longitudinal waves.

6.A.2 For propagation, mechanical waves require a medium, while electromagnetic waves do not require a physical medium.

Examples should include light traveling through a vacuum and sound not traveling through a vacuum.

6.A.2.1 The student is able to describe sound in terms of transfer of energy and momentum in a medium and relate the concepts to everyday examples.

6.A.3 The amplitude is the maximum displacement of a wave from its equilibrium value.

6.A.3.1 The student is able to use graphical representation of a periodic mechanical wave to determine the amplitude of the wave.

6.A.4 Classically, the energy carried by a wave depends upon and increases with amplitude. Examples should include sound waves.

6.A.4.1 The student is able to 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.

6.B.1 For a periodic wave, the period is the repeat time of the wave. The frequency is the number of repetitions of the wave per unit time.

6.B.1.1 The student is able to 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.

6.B.2 For a periodic wave, the wavelength is the repeat distance of the wave.

6.B.2.1 The student is able to use a visual representation of a periodic mechanical wave to determine wavelength of the wave.

6.B.4 For a periodic wave, wavelength is the ratio of speed over frequency.

6.B.4.1 The student is able to design an experiment to determine the relationship between periodic wave speed, wavelength, and frequency and relate these concepts to everyday examples.

6.B.5 The observed frequency of a wave depends on the relative motion of source and observer. This is a qualitative treatment only.

6.B.5.1 The student is able to create or use a wave front diagram to demonstrate or interpret qualitatively the observed frequency of a wave, dependent upon relative motions of source and observer.

6.D.1 Two or more wave pulses can interact in such a way as to produce amplitude variations in the resultant wave. When two pulses cross, they travel through each other; they do not bounce off each other. Where the pulses overlap, the resulting displacement can be determined by adding the displacements of the two pulses. This is called superposition.

6.D.1.1 The student is able to use representations of individual pulses and construct representations to model the interaction of two wave pulses to analyze the superposition of two pulses.

6.D.1.2 The student is able to design a suitable experiment and analyze data illustrating the superposition of mechanical waves (only for wave pulses or standing waves).

6.D.1.3 The student is able to 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.

6.D.2 Two or more traveling waves can interact in such a way as to produce amplitude variations in the resultant wave. 6.D.2.1 The student is able to 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. 6.D.3 Standing waves are the result of the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. Examples should include waves on a fixed length of string, and sound waves in both closed and open tubes. 6.D.3.1 The student is able to 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. 6.D.3.2 The student is able to 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. 6.D.3.3 The student is able to plan data collection strategies, predict the outcome based on the relationship under test, perform data analysis, evaluate evidence compared to the prediction, explain any discrepancy and, if necessary, revise the relationship among variables responsible for establishing standing waves on a string or in a column of air. 6.D.3.4 The student is able to describe representations and models of situations in which standing waves result from the addition of incident and reflected waves confined to a region. 6.D.4 The possible wavelengths of a standing wave are determined by the size of the region to which it is confined. a. A standing wave with zero amplitude at both ends can only have certain wavelengths. Examples should include fundamental frequencies and harmonics. b. Other boundary conditions or other region sizes will result in different sets of possible wavelengths. 6.D.4.1 The student is able to 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. 6.D.4.2 The student is able to calculate wavelengths and frequencies (if given wave speed) of standing waves based on boundary conditions and length of region within which the wave is confined, and calculate numerical values of wavelengths and frequencies. Examples should include musical instruments. 6.D.5 Beats arise from the addition of waves of slightly different frequency. a. Because of the different frequencies, the two waves are sometimes in phase and sometimes out of phase. The resulting regularly spaced amplitude changes are called beats. Examples should include the tuning of an instrument. b. The beat frequency is the difference in frequency between the two waves. 6.D.5.1 The student is able to use a visual representation to explain how waves of slightly different frequency give rise to the phenomenon of beats. **2.5 WEEKS**	
4TH Nine weeks / **Objectives**	**Vocabulary**
9. Electrostatics 1.A.1 A system is an object or collection of objects. Objects are treated as having no internal structure.	Charge Coulombs Law

a. A collection of particles in which internal interactions change little or not at all, or in which changes in these interactions are irrelevant to the question addressed, can be treated as an object.

b. Some elementary particles are fundamental particles (e.g., electrons). Protons and neutrons are composed of fundamental particles (i.e., quarks) and might be treated as either systems or objects, depending on the question being addressed.

c. The electric charges on neutrons and protons result from their quark compositions.

1.B.1 Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system.

a. An electrical current is a movement of charge through a conductor.

b. A circuit is a closed loop of electrical current.

1.B.1.1 The student is able to make claims about natural phenomena based on conservation of electric charge.

1.B.1.2 The student is able to 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.

1.B.2 There are only two kinds of electric charge. Neutral objects or systems contain equal quantities of positive and negative charge, with the exception of some fundamental particles that have no electric charge.

a. Like-charged objects and systems repel, and unlike-charged objects and systems attract.

1.B.2.1 The student is able to construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices.

1.B.3 The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.

a. The magnitude of the elementary charge is equal to 1.6×10^{-19} coulombs.

b. Electrons have a negative elementary charge; protons have a positive elementary charge of equal magnitude, although the mass of a proton is much larger than the mass of an electron.

1.B.3.1 The student is able to challenge the claim that an electric charge smaller than the elementary charge has been isolated. [See Science Practices 1.5, 6.1, and 7.2]

3.C.2 Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.

a. Electric forces dominate the properties of the objects in our everyday experiences. However, the large number of particle interactions that occur make it more convenient to treat everyday forces in terms of nonfundamental forces called contact forces, such as normal force, friction, and tension.

b. Electric forces may be attractive or repulsive, depending upon the charges on the objects involved.

3.C.2.1 The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges.

Interactions between collections of electric point charges are not covered in Physics 1 and instead are restricted to Physics 2.

3.C.2.2 The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces.

3.G.1 Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales. 3.G.1.1 The student is able to articulate situations when the gravitational force is the dominate force and when the electromagnetic, weak, and strong forces can be ignored. 5.A.2 For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings. 5.A.2.1 The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. **2.5 WEEKS**	
10. Current Electricity 1.E.2 Matter has a property called resistivity. a. The resistivity of a material depends on its molecular and atomic structure. b. The resistivity depends on the temperature of the material. 1.E.2.1 The student is able to choose and justify the selection of data needed to determine the resistivity for a given material. 5.B.3 The change in electric potential in a circuit is the change in potential energy per unit charge. Physics 1: only in the context of circuits. 5.B.9 Kirchhoff's loop rule describes conservation of energy in electrical circuits. The application of Kirchhoff's laws to circuits is introduced in Physics 1 and further developed in Physics 2 in the context of more complex circuits, including those with capacitors. a. Energy changes in simple electrical circuits are conveniently represented in terms of energy change per charge moving through a battery and a resistor. b. Since electric potential difference times charge is energy, and energy is conserved, the sum of the potential differences about any closed loop must add to zero. c. The electric potential difference across a resistor is given by the product of the current and the resistance. d. The rate at which energy is transferred from a resistor is equal to the product of the electric potential difference across the resistor and the current through the resistor. 5.B.9.1 The student is able to 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). 5.B.9.2 The student is able to apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule ($\Sigma\Delta V = 0$) in a circuit with only a battery and resistors either in series or in, at most, one pair of parallel branches. 5.B.9.3 The student is able to 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.	Current Voltage Power Kirchhoff Charge

5.C.3 Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit. Examples should include circuits that combine resistors in series and parallel. Covers circuits with resistors in series, with at most one parallel branch, one battery only. 5.C.3.1 The student is able to 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. 5.C.3.2 The student is able to 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. 5.C.3.3 The student is able to use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit. **3 WEEKS**	