Revised:5/22/2023
Board Approved:

AP Physics A Yearly Standards

Units	Priority Standards	Supporting Standards	Science Practices
Unit 1	**3.A** All forces share certain common characteristics when considered by observers in inertial reference frames. **4.A** The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\overline{a} = \frac{\Sigma F}{m}$.	**3.A.1.1** Express the motion of an object using narrative, mathematical, and graphical representations. [SP 1.5, 2.1, 2.2] **3.A.1.2** Design an experimental investigation of the motion of an object. [SP 4.2] **3.A.1.3** 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. [SP 5.1] **4.A.1.1** Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively. [SP 1.2, 1.4, 2.3, 6.4] **4.A.2.1** 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. [SP 6.4] **4.A.2.3** Create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the	**1.2** The student can describe representations and models of natural or man-made phenomena and systems in the domain.* **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain. **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 quantities that describe natural phenomena.* **4.2** The student can design a plan for collecting data to answer a particular scientific question. **5.1** The student can analyze data to identify patterns or relationships. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models

		motion of the center of mass of a system. [SP 1.4, 2.2]	
Unit 2	**1.A** The internal structure of a system determines many properties of the system. **2.B** A gravitational field is caused by an object with mass. **3.C** At the macroscopic level, forces can be categorized as either long-range (action-at a-distance) forces or contact forces. **1.C** Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles. **3.A** All forces share certain common characteristics when considered by observers in inertial reference frames. **3.B** Classically, the acceleration of an object interacting with other objects can be predicted by using $\overline{a} = \frac{\Sigma F}{m}$. **4.A** The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\overline{a} = \frac{\Sigma F}{m}$.	**1.A.5.1** Model verbally or visually the properties of a system based on its substructure and relate this to changes in the system properties over time as external variables are changed. [SP 1.1, 7.1] **2.B.1.1** 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. [SP 2.2, 7.2] **3.C.4.1** Make claims about various contact forces between objects based on the microscopic cause of these forces. [SP 6.1] **3.C.4.2** Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [SP 6.2] **1.C.1.1** Design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration. [SP 4.2] **1.C.3.1** Design a plan for collecting data to measure gravitational mass and inertial mass and to distinguish between the two experiments. [SP 4.2] **3.A.2.1** Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [SP 1.1] **3.A.3.1** Analyze a scenario and make	**1.1** The student can create representations and models of natural or man-made phenomena and systems in the domain.* **7.1** The student can connect phenomena and models across spatial and temporal scales.* **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas. **6.1** The student can justify claims with evidence. **6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.* **4.2** The student can design a plan for collecting data to answer a particular scientific question. **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas. **1.5** The student can re-express key elements of natural phenomena across

		claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [SP 6.4, 7.2] **<u>3.A.3.2</u>** Challenge a claim that an object can exert a force on itself. [SP 6.1] **<u>3.A.3.3</u>** Describe a force as an interaction between two objects, and identify both objects for any force. [SP 1.4] **<u>3.A.4.1</u>** Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action/reaction pairs of forces. [SP 1.4, 6.2] **<u>3.A.4.2</u>** Use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [SP 6.4, 7.2] **<u>3.A.4.3</u>** Analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [SP 1.4] **<u>3.B.1.1</u>** 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. [SP 6.4, 7.2] **<u>3.B.1.2</u>** 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. [SP 4.2, 5.1]	multiple representations in the domain. **<u>5.1</u>** The student can analyze data to identify patterns or relationships..

		3.B.1.3 Re-express a free-body diagram into a mathematical representation, and solve the mathematical representation for the acceleration of the object. [SP 1.5, 2.2] **3.B.2.1** Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [SP 1.1, 1.4, 2.2] **4.A.1.1** Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively. [SP 1.2, 1.4, 2.3, 6.4] **4.A.2.2** Evaluate, using given data, whether all the forces on a system or all the parts of a system have been identified. [SP 5.3] **4.A.3.1** 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. [SP 2.2] **4.A.3.2** 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. [SP 1.4]	
Unit 3	**2.A** 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.	**3.G.1.1** Articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored. [SP 7.1] **3.C.1.1** Use Newton's law of gravitation to calculate the gravitational force that	**7.1** The student can connect phenomena and models across spatial and temporal scales. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **7.2** The student can connect concepts

	3.G Certain types of forces are considered fundamental. **3.C** At the macroscopic level, forces can be categorized as either long-range (action-at a-distance) forces or contact forces. **2.B** A gravitational field is caused by an object with mass. **1.C** Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles. **4.A** The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\overline{a} = \frac{\Sigma F}{m}$. **3.B** Classically, the acceleration of an object interacting with other objects can be predicted by using $\overline{a} = \frac{\Sigma F}{m}$. **3.A** All forces share certain common characteristics when considered by observers in inertial reference frames.	two objects exert on each other and use that force in contexts other than orbital motion. [SP 2.2] **3.C.1.2** Use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion (for circular orbital motion only in Physics 1). [SP 2.2] **2.B.1.1** 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. [SP 2.2, 7.2] **2.B.2.1** Apply $g = G\frac{m}{r^2}$ to calculate the gravitational field due to an object with mass m, where the field is a vector directed toward the center of the object of mass m. [SP 2.2] **2.B.2.2** Approximate a numerical value of the gravitational field (g) near the surface of an object from its radius and mass relative to those of Earth or other reference objects. [SP 2.2] **1.C.3.1** Design a plan for collecting data to measure gravitational mass and to measure inertial mass and to distinguish between the two experiments. [SP 4.2] **4.A.2.2** Evaluate, using given data, whether all the forces on a system or whether all the parts of a system have been identified. [SP 5.3] **3.B.1.2** 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	in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.* **4.2** The student can design a plan for collecting data to answer a particular scientific question **5.3** The students can evaluate the evidence provided by data sets in relation to a particular scientific question. **1.1** The student can create representations and models of natural or man-made phenomena and systems in the domain. **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain **5.1** The student can analyze data to identify patterns or relationships.* **2.1** The student can justify the selection of a mathematical routine to solve problems. **6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models.

		between the net force and the vector sum of the individual forces. [SP 4.2, 5.1] **<u>3.B.1.3</u>** Re-express a free-body diagram representation into a mathematical representation, and solve the mathematical representation for the acceleration of the object. [SP1.5, 2.2] **<u>3.B.2.1</u>** Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [SP 1.1, 1.4, 2.2] **<u>3.A.1.1</u>** Express the motion of an object using narrative, mathematical, and graphical representations. [SP 1.5, 2.1, 2.2] **<u>3.A.1.2</u>** Design an experimental investigation of the motion of an object. [SP 4.2] **<u>3.A.1.3</u>** Analyze experimental data describing the motion of an object and express the results of the analysis using narrative, mathematical, and graphical representations. [SP 5.1] **<u>3.A.2.1</u>** Represent forces in diagrams or mathematically, using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [SP 1.1] **<u>3.A.3.1</u>** 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. [SP 6.4, 7.2] **<u>3.A.3.3</u>** Describe a force as an interaction between two objects and identify both objects for any force. [SP	

		1.4] **3.A.4.1** Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action/reaction pairs of forces. [SP 1.4, 6.2] **3.A.4.2** Use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [SP 6.4, 7.2] **3.A.4.3** Analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [SP 1.4]	
Unit 4	5.A 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. 3.E A force exerted on an object can change the kinetic energy of the object. 4.C Interactions with other objects or systems can change the total energy of a system. 5.B The energy of a system is conserved.	**5.A.2.1** Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [SP 6.4, 7.2] **3.E.1.1** 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. [SP 6.4, 7.2] **3.E.1.2** Use net force and velocity vectors to determine qualitatively whether the kinetic energy of an object would increase, decrease, or remain unchanged. [SP 1.4] **3.E.1.3** 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. [SP 1.4, 2.2] **3.E.1.4** Apply mathematical routines to	**6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas. **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **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. **1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain. **4.2** The student can design a plan for collecting data to answer a particular

		determine the change in kinetic energy of an object given the forces on the object and the displacement of the object. [SP 2.2] **4.C.1.1** 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. [SP 1.4, 2.1, 2.2] **4.C.1.2** Predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system. [SP 6.4] **4.C.2.1** 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. [SP 6.4] **4.C.2.2** Apply the concepts of conservation of energy and the work-energy theorem to determine qualitatively and/or quantitatively that work done on a two-object system in linear motion will change the kinetic energy of the center of mass of the system, the potential energy of the systems, and/or the internal energy of the system. [SP 1.4, 2.2, 7.2] **5.B.1.1** 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. [SP 1.4, 2.2] **5.B.1.2** Translate between a representation of a single object, which	scientific question. **5.1** The student can analyze data to identify patterns or relationships.

		can only have kinetic energy, and a system that includes the object, which may have both kinetic and potential energies. [SP 1.5] **5.B.2.1** 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. [SP 1.4, 2.1] **5.B.3.1** Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [SP 2.2, 6.4, 7.2] **5.B.3.2** Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. [SP 1.4, 2.2] **5.B.3.3** 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. [SP 1.4, 2.2] **5.B.4.1** Describe and make predictions about the internal energy of systems. [SP 6.4, 7.2] **5.B.4.2** Calculate changes in kinetic energy and potential energy of a system using information from representations of that system. [SP 1.4, 2.1, 2.2] **5.B.5.1** 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. [SP 4.2, 5.1] **5.B.5.2** 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. [SP 4.2, 5.1] **5.B.5.3** 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. [SP 1.4, 2.2, 6.4] **5.B.5.4** Make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). [SP 6.4, 7.2] **5.B.5.5** 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. [SP 2.2, 6.4]	
Unit 5	**3.D** A force exerted on an object can change the momentum of the object. **4.B** Interactions with other objects or systems can change the total linear momentum of a system. **5.A** 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	**3.D.1.1** 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. [SP 4.1] **3.D.2.1** Justify the selection of routines for the calculation of the relationships between changes in momentum of an object, average force, impulse, and time of interaction. [SP 2.1] **3.D.2.2** Predict the change in	**2.1** The student can justify the selection of a mathematical routine to solve problems. **4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question. **4.2** The student can design a plan for collecting data to answer a particular scientific question. **5.1** The student can analyze data to identify patterns or relationships. **6.4** The student can make claims and

	interactions with other systems. **5.D** The linear momentum of a system is conserved	momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [SP 6.4] **3.D.2.3** 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. [SP 5.1] **3.D.2.4** Design a plan for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time. [SP 4.2] **4.B.1.1** 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.). [SP 1.4, 2.2] **4.B.1.2** 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. [SP 5.1] **4.B.2.1** Apply mathematical routines to calculate the change in momentum of a system by analyzing the average force exerted over a certain time on the system. [SP 2.2] **4.B.2.2** Perform an analysis on data presented as a force-time graph and predict the change in momentum of a system. [SP 5.1] **5.A.2.1** Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [SP 6.4, 7.2] **5.D.1.1** Make qualitative predictions	predictions about natural phenomena based on scientific theories and models **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.* **3.2** The student can refine scientific questions **4.4** The student can evaluate sources of data to answer a particular scientific question.* **5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question

		about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions. [SP 6.4, 7.2] **5.D.1.2** Apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and qualitatively in two-dimensional situations. [SP 2.2, 3.2, 5.1, 5.3] **5.D.1.3** Apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy. [SP 2.1, 2.2] **5.D.1.4** 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. [SP 4.2, 5.1, 5.3, 6.4] **5.D.1.5** 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. [SP 2.1, 2.2] **5.D.2.1** 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. [SP 6.4, 7.2] **5.D.2.2** Plan data-collection strategies to test the law of conservation of momentum in a two-object collision that is elastic or inelastic and analyze the resulting data graphically. [SP 4.1, 4.2, 5.1] **5.D.2.3** Apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [SP 6.4, 7.2] **5.D.2.4** Analyze data that verify conservation of momentum in collisions with and without an external frictional force. [SP 4.1, 4.2, 4.4, 5.1, 5.3] **5.D.2.5** 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. [SP 2.1, 2.2] **5.D.3.1** 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). [SP 6.4]	

Unit 6	**3.B** Classically, the acceleration of an object interacting with other objects can be predicted by using $\overline{a} = \frac{\Sigma F}{m}$ **5.B** The energy of a system is conserved.	**3.B.3.1** Predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. [SP 6.4, 7.2] **3.B.3.2** Design a plan and collect data in order to ascertain the characteristics of the motion of a system undergoing oscillatory motion caused by a restoring force. [SP 4.2] **3.B.3.3** 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. [SP 2.2, 5.1] **3.B.3.4** Construct a qualitative and/ or quantitative explanation of oscillatory behavior given evidence of a restoring force. [SP 2.2, 6.2] **5.B.2.1** 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. [SP 1.4, 2.1] **5.B.3.1** Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [SP 2.2, 6.4, 7.2] **5.B.3.2** Make quantitative calculations	**2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **4.2** The student can design a plan for collecting data to answer a particular scientific question. **5.1** The student can analyze data to identify patterns or relationships. **6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas. **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **2.1** The student can justify the selection of a mathematical routine to solve problems.

		of the internal potential energy of a system from a description or diagram of that system. [SP 1.4, 2.2] **5.B.3.3** 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. [SP 1.4, 2.2] **5.B.4.1** Describe and make predictions about the internal energy of systems. [SP 6.4, 7.2] **5.B.4.2** Calculate changes in kinetic energy and potential energy of a system using information from representations of that system. [SP 1.4, 2.1, 2.2]	
Unit 7	**3.A** All forces share certain common characteristics when considered by observers in inertial reference frames. **3.F** A force exerted on an object can cause a torque on that object. **4.D** A net torque exerted on a system by other objects or systems will change the angular momentum of the system. **5.E** The angular momentum of a system is conserved.	**3.A.1.1** Express the motion of an object using narrative, mathematical, and graphical representations. [SP 1.5, 2.1, 2.2] **3.F.1.1** Use representations of the relationship between force and torque. [SP 1.4] **3.F.1.2** Compare the torques on an object caused by various forces. [SP 1.4] **3.F.1.3** Estimate the torque on an object caused by various forces in comparison with other situations. [SP 2.3] **3.F.1.4** Design an experiment and analyze data testing a question about torques in a balanced rigid system. [SP 4.1, 4.2, 5.1] **3.F.1.5** Calculate torques on a two-dimensional system in static equilibrium by examining a representation or model (such as a diagram or physical construction). [SP	**1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain. **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 **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **2.3** The student can estimate quantities that describe natural phenomena. **4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question. **4.2** The student can design a plan for collecting data to answer a particular scientific question. **5.1** The student can analyze data to

		1.4, 2.2] **3.F.2.1** Make predictions about the change in the angular velocity about an axis for an object when forces exerted on the object cause a torque about that axis. [SP 6.4] **3.F.2.2** 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. [SP 4.1, 4.2, 5.1] **3.F.3.1** 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. [SP 6.4, 7.2] **3.F.3.2** In an unfamiliar context or using representations beyond equations, justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object. [SP 2.1] **3.F.3.3** 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. [SP 4.1, 4.2, 5.1, 5.3] **4.D.1.1** 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. [SP 1.2, 1.4]	identify patterns or relationships. **5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas **1.2** The student can describe representations and models of natural or man-made phenomena and systems in the domain.* **3.2** The student can refine scientific questions.*

		4.D.1.2 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. [SP 3.2, 4.1, 4.2, 5.1, 5.3] **4.D.2.1** 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. [SP 1.2, 1.4] **4.D.2.2** 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. [SP 4.2] **4.D.3.1** 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. [SP 2.2] **4.D.3.2** Plan a data-collection strategy designed to test the relationship between the change in angular momentum of a system and the product of the average torque applied to the system and the time interval during which the torque is exerted. [SP 4.1, 4.2] **5.E.1.1** Make qualitative predictions about the angular momentum of a	

		system for a situation in which there is no net external torque. [SP 6.4, 7.2] **5.E.1.2** Make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero. [SP 2.1, 2.2] **5.E.2.1** 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. Use qualitative reasoning with compound objects and perform calculations with a fixed set of extended objects and point masses. [SP 2.2]	