**AP Objectives: Forces and Newton’s Laws**

*Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.*

Enduring Understanding 1.A: The internal structure of a system determines many properties of the system.

**Essential Knowledge 1.A.1:** A system is an object or a collection of objects. Objects are treated as having no internal structure.

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.

Enduring Understanding 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.

**Essential Knowledge 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.

**Learning Objective (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.

[See Science Practice 4.2]

**Essential Knowledge 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.

**Essential Knowledge 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.

**Learning Objective (1.C.3.1):**

The student is able to design a plan for collecting data to measure gravitational mass and to measure inertial mass, and to distinguish between the two experiments. [See Science Practice 4.2]

*Big Idea 2: Fields existing in space can be used to explain interactions.*

Enduring Understanding 2.B: A gravitational field is caused by an object with mass.

**Essential Knowledge 2.B.1:** A gravitational field $\rightharpoonaccent{g}$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.

**Learning Objective (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. [See Science Practices 2.2 and 7.2]

*Big Idea 3: The interactions of an object with other objects can be described by forces.*

Enduring Understanding 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.

Boundary Statement: AP Physics 2 has learning objectives under this enduring understanding that focus on electric and magnetic forces and other forces arising in the context of interactions introduced in Physics 2, rather than the mechanical systems introduced in Physics 1.

**Essential Knowledge 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.

**Learning Objective (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. [See Science Practice 1.1]

**Essential Knowledge 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 exerted on the object by other objects.

**Learning Objective (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. [See Science Practices 6.4 and 7.2]

**Learning Objective (3.A.3.2):**

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

[See Science Practice 6.1]

**Learning Objective (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. [See Science Practice 1.4]

**Essential Knowledge 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.

**Learning Objective (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.

[See Science Practices 1.4 and 6.2]

**Learning Objective (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. [See Science Practices 6.4 and 7.2]

**Learning Objective (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.

[See Science Practice 1.4]

Enduring Understanding 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using$ \rightharpoonaccent{a}=\frac{Σ\rightharpoonaccent{F}}{m}$.

Boundary Statement: AP Physics 2 contains learning objectives under this enduring understanding that focus on electric and magnetic forces and other forces arising in the context of interactions introduced in Physics 2, rather than the mechanical systems introduced in Physics 1.

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

**Learning Objective (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. [See Science Practices 6.4 and 7.2]

**Learning Objective (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. [See Science Practices 4.2 and 5.1]

**Learning Objective (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.

[See Science Practices 1.5 and 2.2]

**Essential Knowledge 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.

**Learning Objective (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. [See Science Practices 1.1, 1.4, and 2.2]

*Big Idea 4: Interactions between systems can result in changes in those systems.*

Enduring Understanding 4.A: The acceleration of the center of mass of a system is related to the net force exerted on the system, where$ \rightharpoonaccent{a}=\frac{Σ\rightharpoonaccent{F}}{m}$.

Boundary Statement: Physics 1 includes no calculations of center of mass; the equation is not provided until Physics 2. 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.

**Essential Knowledge 4.A.1:** The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.

**Learning Objective (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 semi-quantitatively. [See Science Practices 1.2, 1.4, 2.3, and 6.4]

**Essential Knowledge 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.

**Learning Objective (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. [See Science Practice 6.4]

**Learning Objective (4.A.2.2):**

The student is able to evaluate using given data whether all the forces on a system or whether all the parts of a system have been identified. [See Science Practice 5.3]

**Learning Objective (4.A.2.3):**

The student is able to create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system. [See Science Practices 1.4 and 2.2]

**Essential Knowledge 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.

**Learning Objective (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. [See Science Practice 2.2]

**Learning Objective (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. [See Science Practice 1.4]