Unit 3: Dynamics
UNIT PLAN

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UNIT NARRATIVE

Unit 3 introduces students to the fundamental concepts of dynamics by building a deep understanding of Newton's Laws and the forces that govern motion. This unit is intimately related to kinematics because forces explain how and why object move the way they do. By the end of this unit students should be able to model and analyze the forces acting on an object or system using FBD and Newton's Three Laws and make claims about the motion of an object/system using the forces acting on the object/system as justification.

The first section of the unit begins with a hands-on inquiry lab for students to develop an intuitive understanding of Newton's First Law by observing patterns between the forces acting on an object, balanced/unbalanced, and the motion of the object, constant velocity/changing velocity (Day 1). Next students will be introduced to the most common forces for introductory physics - force of gravity, normal force, tension, friction. These forces are explored through a combination of interactive demonstrations (Day 3: Force Identification) and student-designed lab investigations (Day 2: Mass vs Weight, Day 5-6: Friction Lab). Students will be introduced to Free Body Diagrams as an important tool for modeling the forces acting on an object/system early in the unit (Day 4) so that the have ample practice with FBD before they start analyzing more complicated scenarios toward the end of this unit. This section concludes with a practice activity where students use all of the concepts from previous lessons to create FBD for the Rocket Sledder simulation for several different scenarios and use their FBDs to make and justify claims about the motion and/or forces of the sledder.

In the next section of the unit students will discover Newton's Second Law and practice using Second Law Equations to make quantitative predictions. During this section students will complete a lab to experimentally determine the variable relationships that define Newton's Second Law (Day 9), create Second Law Equations to represent a FBD and calculate unknown variables (Day 10), use Second Law Equations with velocity-time graphs for claims and calculations (Day 11), and analyze vertical motion scenarios using Second Law Equations and FBD (Day 13). After completing this section students will take the Mid-Unit Exam.
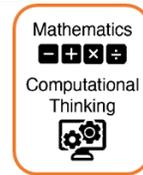
Next is another hands-on inquiry station rotation lab where students have the opportunity to deduce Newton's Third Law (Day 16) by drawing interaction diagrams and 3 FBDs for scenarios involving simple two-object systems. This will also be students introduction to systems. Next students will practice identifying Third Law Force Pairs in scenarios (Day 17). Then students will analyze classic physics scenarios involving two object systems.

First students will experimentally determine the variable relationships that define the acceleration of an Atwood Device (Day 18) and then practice analyzing Atwood Device scenarios using FBD, Second Law Equations, and Interaction diagrams (Day 19). Then students will be ready to analyze the more complicated Modified Atwood scenarios, that can also include friction, using all the same models and physics concepts (Day 20).

The unit concludes with students analyzing two types of scenarios that require additional techniques, beyond everything used throughout the unit. Scenarios that include forces acting at an angle (Day 21) require the use of perpendicular vector components. Inclined plane scenarios are analyzed next because they also require the use of vector components and are most easily analyzed by titling the x axis to be parallel with the incline.

Focus on Disciplinary Literacy
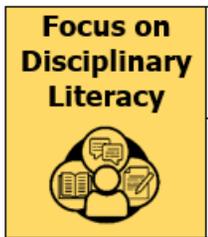
In science, disciplinary literacy is synonymous with the science and engineering practices. The SEPs are the context through which all science concepts should be taught. In the lessons, you will find the Science and Engineering practices icons when the SEPs are being explicitly used by students.

Asking Questions Defining Problems | Developing and Using Models | Planning and Carrying Out Investigations | Analyzing and Interpreting Data | Mathematics Computational Thinking | Constructing Explanations Designing Solutions | Engaging in Argument from Evidence | Obtaining, Evaluating, and Communicating Information

UNPACKED CONTENT STANDARDS

TEKS Physics Standards

Standard ID	Standard Description
C.5	The student knows and applies the laws governing motion in a variety of situations. The student is expected to:
C.5.D	describe and analyze acceleration in uniform circular and horizontal projectile motion in two dimensions using equations;
C.5.E	explain and apply the concepts of equilibrium and inertia as represented by Newton's first law of motion using relevant real-world examples such as rockets, satellites, and automobile safety devices;
C.5.F	calculate the effect of forces on objects, including tension, friction, normal, gravity, centripetal, and applied forces, using free body diagrams and the relationship between force and acceleration as represented by Newton's second law of motion;
C.5.G	illustrate and analyze the simultaneous forces between two objects as represented in Newton's third law of motion using free body diagrams and in an experimental design scenario; and

College Board AP Physics Standards

Note: All Learning Objectives and Essential Knowledge in red will not be included in this unit.

Topic #	Topic	LO #	Learning Objective	EO #	Essential Knowledge
2.1	Systems and Center of Mass	2.1.A	Describe the properties and interactions of a system.	2.1.A.1	System properties are determined by the interactions between objects within the system.
				2.1.A.2	If the properties or interactions of the constituent objects within a system are not important in modeling the behavior of the macroscopic system, the system can itself be treated as a single object.
				2.1.A.3	Systems may allow interactions between constituent parts of the system and the environment, which may result in the transfer of energy or mass.
				2.1.A.4	Individual objects within a chosen system may behave differently from each other as well as from the system as a whole.
				2.1.A.5	The internal structure of a system affects the analysis of that system.
				2.1.A.6	As variables external to a system are changed, the system's substructure may change.
		2.1.B	Describe the location of a system's center of mass with respect to the system's constituent parts.	2.1.B.1	For systems with symmetrical mass distributions, the center of mass is located on lines of symmetry.
				2.1.B.2	The location of a system's center of mass along a given axis can be calculated using the equation --> $x_{cm} = \frac{\Sigma m_i x_i}{\Sigma m_i}$
				2.1.B.3	A system can be modeled as a singular object that is located at the system's center of mass.
				BOUNDARY STATEMENT: *AP Physics 1 only expects students to calculate the center of mass for systems of five or fewer particles arranged in a two-dimensional configuration or for systems that are highly symmetrical.*	

2.2	Forces and Free-Body Diagrams	2.2.A	Describe a force as an interaction between two objects or systems.	2.2.A.1	Forces are vector quantities that describe the interactions between objects or systems. i. A force exerted on an object or system is always due to the interaction of that object with another object or system. ii. An object or system cannot exert a net force on itself.
				2.2.A.2	Contact forces describe the interaction of an object or system touching another object or system and are macroscopic effects of interatomic electric forces.
		2.2.B	Describe the forces exerted on an object or system using a free-body diagram.	2.2.B.1	Free-body diagrams are useful tools for visualizing forces being exerted on a single object or system and for determining the equations that represent a physical situation.
				2.2.B.2	The free-body diagram of an object or system shows each of the forces exerted on the object by the environment.
				2.2.B.3	Forces exerted on an object or system are represented as vectors originating from the representation of the center of mass, such as a dot. A system is treated as though all of its mass is located at the center of mass.
				2.2.B.4	A coordinate system with one axis parallel to the direction of acceleration of the object or system simplifies the translation from free body diagram to algebraic representation. For example, in a free-body diagram of an object on an inclined plane, it is useful to set one axis parallel to the surface of the incline.
		BOUNDARY STATEMENT: *AP Physics 1 only expects students to depict the forces exerted on objects, not the force components on free-body diagrams. On the AP Physics exams, individual forces represented on a free-body diagram must be drawn as individual straight arrows, originating on the dot and pointing in the direction of the force. Individual forces that are in the same direction must be drawn side by side, not overlapping.*			
2.3	Newton's Third Law	2.3.A	Describe the interaction of two objects using Newton's third law and a representation of paired forces exerted on each object.	2.3.A.1	Newton's third law describes the interaction of two objects in terms of the paired forces that each exerts on the other. F(a on b) = - F (b on a)
				2.3.A.2	Interactions between objects within a system (internal forces) do not influence the motion of a system's center of mass.
				2.3.A.3	Tension is the macroscopic net result of forces that segments of a string, cable, chain, or similar system exert on each other in response to an external force. i. An ideal string has negligible mass and does not stretch when under tension. ii. The tension in an ideal string is the same at all points within the string. iii. In a string with nonnegligible mass, tension may not be the same at all points within the string. iv. An ideal pulley is a pulley that has negligible mass and rotates about an axle through its center of mass with negligible friction.
		BOUNDARY STATEMENT: *AP Physics 1 only expects students to describe tension qualitatively in a string, cable, chain, or similar system with mass. For example, students might note that the tension in a hanging chain is greater toward the top of the chain.* **BOUNDARY STATEMENT:** *The interaction between objects or systems at a distance is limited to gravitational forces in AP Physics 1. In AP Physics 2, gravitational, electric, and magnetic forces may be considered.*			
2.4		2.4.A		2.4.A.1	The net force on a system is the vector sum of all forces exerted on the system.

				2.4.A.2	Translational equilibrium is a configuration of forces such that the net force exerted on a system is zero. **Derived equation → $\Sigma F = 0$**
	Newton's First Law		Describe the conditions under which a system's velocity remains constant.	2.4.A.3	Newton's first law states that if the net force exerted on a system is zero, the velocity of that system will remain constant.
				2.4.A.4	Forces may be balanced in one dimension but unbalanced in another. The system's velocity will change only in the direction of the unbalanced force.
				2.4.A.5	An inertial reference frame is one from which an observer would verify Newton's first law of motion.
2.5	**Newton's Second Law**	2.5.A	Describe the conditions under which a system's velocity changes.	2.5.A.1	Unbalanced forces are a configuration of forces such that the net force exerted on a system is not equal to zero.
				2.5.A.2	Newton's second law of motion states that the acceleration of a system's center of mass has a magnitude proportional to the magnitude of the net force exerted on the system and is in the same direction as that net force. **Relevant equation --> $a_{sys} = \dfrac{\Sigma F}{m_{sys}} = \dfrac{F_{net}}{m_{sys}}$**
				2.5.A.3	The velocity of a system's center of mass will only change if a nonzero net external force is exerted on that system.
2.6	**Gravitational Force**	2.6.A	Describe the gravitational interaction between two objects or systems with mass.	2.6.A.1	Newton's law of universal gravitation describes the gravitational force between two objects or systems as directly proportional to each of their masses and inversely proportional to the square of the distance between the systems' centers of mass. **Relevant equation --> $\left\lvert F_g \right\rvert = G \dfrac{m_1 m_2}{r^2}$** i. The gravitational force is attractive. ii. The gravitational force is always exerted along the line connecting the centers of mass of the two interacting systems. iii. The gravitational force on a system can be considered to be exerted on the system's center of mass.
				2.6.A.2	A field models the effects of a noncontact force exerted on an object at various positions in space. i. The magnitude of the gravitational field created by a system of mass M at a point in space is equal to the ratio of the gravitational force exerted by the system on a test object of mass m to the mass of the test object. **Derived equation --> $\lvert g \rvert = \dfrac{\lvert F_g \rvert}{m} = G \dfrac{M}{r^2}$** ii. If the gravitational force is the only force exerted on an object, the observed acceleration of the object (in m/s2) is numerically equal to the magnitude of the gravitational field strength (in N/Kg) at that location.
				2.6.A.3	The gravitational force exerted by an astronomical body on a relatively small nearby object is called weight. **Derived Equation --> $Weight = F_g = mg$**
		2.6.B	Describe situations in which the gravitational	2.6.B.1	If the gravitational force between two systems' centers of mass has a negligible change as the relative position of the two systems changes, the gravitational force can be considered constant at all points between the initial and final positions of the systems.

				force can be considered constant.	2.6.B.2	Near the surface of Earth, the strength of the gravitational field is **g = 10 N/kg**
			2.6.C	Describe the conditions under which the magnitude of a system's apparent weight is different from the magnitude of the gravitational force exerted on that system.	2.6.C.1	The magnitude of the apparent weight of a system is the magnitude of the normal force exerted on the system.
					2.6.C.2	If the system is accelerating, the apparent weight of the system is not equal to the magnitude of the gravitational force exerted on the system.
					2.6.C.3	A system appears weightless when there are no forces exerted on the system or when the force of gravity is the only force exerted on the system.
					2.6.C.4	The equivalence principle states that an observer in a non-inertial reference frame is unable to distinguish between an object's apparent weight and the gravitational force exerted on the object by a gravitational field.
			2.6.D	Describe inertial and gravitational mass.	2.6.D.1	Objects have inertial mass, or inertia, a property that determines how much an object's motion resists changes when interacting with another object.
					2.6.D.2	Gravitational mass is related to the force of attraction between two systems with mass.
					2.6.D.3	Inertial mass and gravitational mass have been experimentally verified to be equivalent.
2.7	**Kinetic and Static Friction**	2.7.A		Describe kinetic friction between two surfaces	2.7.A.1	Kinetic friction occurs when two surfaces in contact move relative to each other. i. The kinetic friction force is exerted in a direction opposite to the motion of each surface relative to the other surface. ii. The force of friction between two surfaces does not depend on the size of the surface area of contact.
					2.7.A.2	The magnitude of the kinetic friction force exerted on an object is the product of the normal force the surface exerts on the object and the coefficient of kinetic friction. **Relevant equation --> $\left\lvert F_{f,s}\right\rvert = \left\lvert \mu_k F_n\right\rvert$** i. The coefficient of kinetic friction depends on the material properties of the surfaces that are in contact. ii. Normal force is the perpendicular component of the force exerted on an object by the surface with which it is in contact; it is directed away from the surface.
		2.7.B		Describe static friction between two surfaces.	2.7.B.1	Static friction may occur between the contacting surfaces of two objects that are not moving relative to each other.
					2.7.B.2	Static friction adopts the value and direction required to prevent an object from slipping or sliding on a surface. **Relevant equation --> $\left\lvert F_{f,s}\right\rvert \leq \left\lvert \mu_s F_n\right\rvert$** i. Slipping and sliding refer to situations in which two surfaces are moving relative to each other. ii. There exists a maximum value for which static friction will prevent an object from slipping on a given surface. **Derive Equation --> $F_{f,s,max} = \mu_s F_n$**
					2.7..3	The coefficient of static friction is typically greater than the coefficient of kinetic friction for a given pair of surfaces.
2.8	**Spring Forces**	2.8.A			2.8.A.1	An ideal spring has negligible mass and exerts a force that is proportional to the change in its length as measured from its relaxed length.

| | | | Describe the force exerted on an object by an ideal spring | 2.8.A.2 | The magnitude of the force exerted by an ideal spring on an object is given by <mark>Hooke's law</mark> → $F_s = -k\Delta x$ |
| | | | | 2.8.A.3 | The force exerted on an object by a spring is always directed toward the equilibrium position of the object–spring system. |

UNDERSTANDINGS AND QUESTIONS

Important big ideas and processes for the unit.

Key Understandings

- ❑ Balanced forces (zero net force) produce constant velocity motion
- ❑ Unbalanced forces (non-zero net force) produce changing velocity (accelerated) motion
- ❑ The weight of an object is the force of gravity on the object and may be defined as the mass times the acceleration of gravity. Measured in Newtons.
- ❑ Equation: $F_g = mg$
- ❑ All Forces are measured in the unit of Newtons (N).
- ❑ Gravitational Force (Weight/points down to the center of the planet)
- ❑ Normal Force (Force Perpendicular to a Surface)
- ❑ Friction Force (Parallel to Surfaces but Opposite direction of Motion)
- ❑ Tension Force (Force toward and caused by a String, Rope, or Pulley)
- ❑ Gravitational Force (Weight/points down to the center of the planet)
- ❑ Normal Force (Force Perpendicular of a Surface)
- ❑ Friction Force (Parallel to Surfaces but Opposite direction of Motion)
- ❑ Tension Force (Force toward and caused by a String, Rope, or Pulley)
- ❑ Free body diagrams include only forces acting on an object modeled as arrows starting on the object (usually at the center) and point away from the object.
- ❑ Friction force (F_f) is the force resisting the relative motion of surfaces sliding against each other.
- ❑ Normal force and coefficient of friction have direct, proportional relationships with friction force
- ❑ A coefficient of friction (μ) is a value without units (usually <1) that describes the relationship between the force of friction between two surfaces sliding against each other based on the interactions of materials.
- ❑ Equation: $F_F = \mu N$ (sometimes called the FuN formula)
- ❑ There are two coefficients of friction for each pair of surfaces – static and kinetic.
- ❑ Static friction can be any magnitude between zero and the maximum value, as calculated by the friction equation.
- ❑ Kinetic friction is always smaller than max static friction.
- ❑ Net force is the vector sum of the forces acting on an object
- ❑ Net force has a direct relationship with the acceleration of an object
- ❑ Mass of an object has an inverse relationship with acceleration
- ❑ The acceleration of an object is dependent upon ONLY two variables - the net force acting upon the object and the mass of the object

- ❑ Equation (Newton's Second Law): $a = \frac{F_{net}}{m}$
- ❑ Create a FBD to represent a scenario
- ❑ Second Law Equation: $\Sigma F = ma$
- ❑ Create Second Law Equations to represent a scenario
- ❑ Newton's second law must be use separately for the horizontal and vertical directions (like projectile motion analysis)
- ❑ Acceleration can be found from the slope of a V-t graph
- ❑ Acceleration is proportional to, and in the same direction as the net force on the object
- ❑ Second Law Equation: $\Sigma F = ma$
- ❑ Given a description of an objects motion (narrative or motion graphs) then we can make prediction about the forces and net force on an object
- ❑ Given the forces or net force on an object (narrative or FBD) then we can predict the motion of the object
- ❑ Acceleration can be found from the slope of a V-t graph and is proportional to, and in the same direction as the net force on the object
- ❑ Second Law Equation: $\Sigma F = ma$
- ❑ If we have a description of the motion (narrative or motion graph) then we can describe the forces and net force on an object
- ❑ If we know the forces or net force on an object (diagram or FBD) then we can describe the motion of the object
- ❑ A scale reading is the Normal force
- ❑ Normal force must be greater than F_g when the elevator to accelerate upward
- ❑ Normal force must be less than F_g for the elevator to accelerate downward
- ❑ Normal force must be equal to F_g to move with constant velocity
- ❑ ALL forces are the result of object interactions, so they always occur in pairs (Newton's Third Law).
- ❑ Force pairs are equal in magnitude and opposite in direction.
- ❑ Force pairs always act on two different objects!
- ❑ Identify the object interactions for a scenario (using interaction diagrams)
- ❑ Describe the Third Law force pairs in a scenario
- ❑ Describe the direction and magnitude of force pairs
- ❑ Distinguish between balanced forces acting on a single object and Third Law force pairs acting on two objects.
- ❑ Physics Systems are groups of objects that interact with each other, often moving together (like Atwood machines)
- ❑ Atwood acceleration is directly proportional to the difference between masses
- ❑ Atwood acceleration is inversely proportional to the total mass of the Atwood system
- ❑ Tension will be the same magnitude on both hanging objects in an Atwood machine *because of the Third Law*
- ❑ Derived equation: $a = \frac{g(m_2 - m_1)}{m_1 + m_2}$
- ❑ Identify the forces acting on both the hanging mass and the block on the surface.
- ❑ Draw an accurate FBD for both objects individually and the system.
- ❑ Create Newton's Second Law equations for each object individually and for the system.
- ❑ Describe qualitatively how the acceleration changes when the mass of the hanging mass and/or the block on the table changes.
- ❑ Describe an angled force into horizontal and vertical components.
- ❑ Explain how the vertical component of an angled force affects the normal force.
- ❑ Explain how the horizontal component of and angled force affects acceleration.

- ❑ Create and label an FBD with weight/Fg, normal, tension (angled), and friction forces.
- ❑ Create Second Law equations in both x- and y-directions to predict motion.
- ❑ Predict qualitatively what happens when the angle of and angled force changes.
- ❑ Identify the forces acting on an object on an incline: weight, normal, and friction.
- ❑ Describe the orientation of the x and y axis used to analyze inclined plane scenarios.
- ❑ Describe the force of gravity using horizontal and vertical components.
- ❑ Create Second Law equations for inclined plane scenarios.
- ❑ Describe how the force of gravity components and the normal force change as the angle of incline changes.

Key Questions

- If an object's motion is known, how can we predict the Net Force and individual forces on the object?
- If the forces on an object are known, how can we predict the motion of the object?
- When Object A pushes/pulls on Object B what is the force of Object B on Object A?
- How do we represent forces on a diagram to help us analyze the forces and motion of objects?

VERTICAL STANDARDS

This section details the **progression** of key student expectations/standards** in the courses **before** and **after** this course. This will help you understand what **prior knowledge skills to build upon** and guide you in knowing what **skills you are preparing your students** for in the subsequent course.

5th Grade Science	6/7 Grade Hybrid Science	8th Grade Science
3-5(7) Force, motion, and energy. The student knows the nature of forces and the patterns of their interactions. The student is expected to: • 5(7)(A) investigate and explain how equal and unequal forces acting on an object cause patterns of motion and transfer of energy; and • 5(7)(B) design a simple experimental investigation that tests the effect of force on an object in a system such as a car on a ramp or a balloon rocket on a string.	**6(7) Force, motion, and energy. The student knows the nature of forces and their role in systems that experience stability or change. The student is expected to:** • 6(7)(A) identify and explain how forces act on objects, including gravity, friction, magnetism, applied forces, and normal forces, using real-world applications; • 6(7)(B) calculate the net force on an object in a horizontal or vertical direction using diagrams and determine if the forces are balanced or unbalanced; and • 6(7)(C) identify simultaneous force pairs that are equal in magnitude and opposite in direction that result from the interactions between objects using Newton's Third Law of Motion. **7(7) Force, motion, and energy. The student describes the cause-and-effect relationship between force and motion. The student is expected to:** • 7(7)(D) analyze the effect of balanced and unbalanced forces on the state of motion of an object using Newton's First Law of Motion.	**8(7) Force, motion, and energy. The student understands the relationship between force and motion within systems. The student is expected to:** • 8(7)(A) calculate and analyze how the acceleration of an object is dependent upon the net force acting on the object and the mass of the object using Newton's Second Law of Motion; and • 8(7)(B) investigate and describe how Newton's three laws of motion act simultaneously within systems such as in vehicle restraints, sports activities, amusement park rides, Earth's tectonic activities, and rocket launches.

VOCABULARY GLOSSARY

Domain-specific words and definitions for this unit.

| Key Content Vocabulary |
| --- |
| **Key Content Vocabulary** |
| **Force** – any push or pull on an object |
| **Force magnitude** - the strength of a force (without +/- directions) |
| **Net Force** – the vector sum of forces acting on an object |
| **Weight (Force of Gravity)** – the force acting on the object due to gravity |
| **Normal Force** – the component of a contact force that is perpendicular to the surface that an object contacts |
| **Tension** – the pulling force transmitted axially by the means of a string, a cable, chain, or similar object |
| **Friction Force** - the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other |
| **Static Friction Force** – the friction between two or more solid objects that are *not moving* relative to each other |
| **Kinetic Friction Force (dynamic friction, sliding friction)** – occurs when two objects are moving relative to each other and rub together (like a sled on the ground) |
| **Coefficient of Friction (μ)** - a dimensionless scalar value which equals the ratio of the force of friction between two bodies and the force pressing them together, either during or at the onset of slipping |
| **Static Friction** - The friction experienced when individuals try to move a stationary object on a surface, without actually triggering any relative motion between the body and the surface on which it is on. |
| **Kinetic Friction** – The friction experienced when two surfaces are in contact and moving relative to each other. |
| **Free Body Diagram** - a diagrammatic representation of a single body or a subsystem of bodies isolated from its surroundings showing all the forces acting on it |
| **Newton's First Law** – states that an object either remains at rest or continues to move at a constant velocity, unless it is acted upon by an external force |
| **Newton's Second Law** – states that the rate of change of momentum of an object is directly proportional to the force applied, or, for an object with constant mass, that the net force on an object is equal to the mass of that object multiplied by the acceleration $$F_{NET} = ma$$ |
| **Newton's Third Law** - states that when one object exerts a force on a second object, that second object exerts a force that is equal in magnitude and opposite in direction on the first object |
| **Atwood Machine** - a laboratory experiment to verify the mechanical laws of motion with constant acceleration. |
| **System** – a collection of objects that are of interest because they have specific interactions or motion together |
| **Ideal pulley** – a pulley that has no mass (and hence no rotational inertia) and no rotational friction |
| **Ideal String** – a string that has no mass and does not stretch |
| **Internal Force** (system) – forces that are the product of interaction between two objects inside of a given system |
| **External Force** (system) – forces that are the product of interaction between one or more objects inside a given system and another object that is outside the system |
| **Angled Force** – a force that is in a direction different than Up-Down-Left-Right, or North-South-East-West |
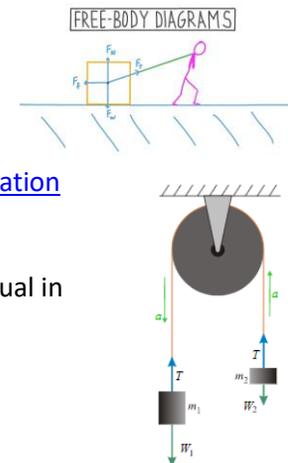
Related Vocabulary					
Constant velocity Constant acceleration Slowing down Speeding up Vector	Balanced forces Unbalanced forces	Air resistance Slip angle			