Verona Public School District
Curriculum Overview

AP Physics C: Mechanics

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Verona Public Schools
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Verona Public Schools Mission Statement:

The mission of the Verona Public Schools, the center of an engaged and supportive community, is to empower students to achieve their potential as active learners and productive citizens through rigorous curricula and meaningful, enriching experiences.

Course Description:

AP Physics C: Mechanics is second-year physics course taught at the introductory college level that utilizes differential and integral calculus to explore the physical world. Students will explore linear and curvilinear motion as a result of constant and non-constant forces, conservation laws, rotational motion, oscillatory motion, and planetary motion as a result of the force of gravity. Students will learn and apply various problem solving skills with an emphasis on symbolic solutions. Approximately 20% of class time will be devoted to laboratory investigations that are primarily inquiry- or discovery-based investigations focusing on the student's' ability to use and interpret graphical data.

Prerequisite(s):

Honors Physics or AP Physics 1, Pre-Calculus, co-requisite of AP Calculus.

Standard 8: Technology Standards	
8.1: Educational Technology: *All students will use digital tools to access, manage, evaluate, and synthesize information in order to solve problems individually and collaborate and to create and communicate knowledge.*	**8.2: Technology Education, Engineering, Design, and Computational Thinking - Programming:** *All students will develop an understanding of the nature and impact of technology, engineering, technological design, computational thinking and the designed world as they relate to the individual, global society, and the environment.*
A. Technology Operations and Concepts B. Creativity and Innovation C. Communication and Collaboration D. Digital Citizenship E. Research and Information Fluency **X** F. Critical thinking, problem solving, and decision making	A. The Nature of Technology: Creativity and Innovation B. Technology and Society **X** C. Design D. Abilities for a Technological World E. Computational Thinking: Programming

SEL Competencies and Career Ready Practices	
Social and Emotional Learning Core Competencies: *These competencies are identified as five interrelated sets of cognitive, affective, and behavioral capabilities*	**Career Ready Practices:** *These practices outline the skills that all individuals need to have to truly be adaptable, reflective, and proactive in life and careers. These are researched practices that are essential to career readiness.*
Self-awareness: The ability to accurately recognize one's emotions and thoughts and their influence on behavior. This includes accurately assessing one's strengths and limitations and possessing a well-grounded sense of confidence and optimism.	**X** CRP2. Apply appropriate academic and technical skills. CRP9. Model integrity, ethical leadership, and effective management. CRP10. Plan education and career paths aligned to personal goals.
Self-management: The ability to regulate one's emotions, thoughts, and behaviors effectively in different situations. This includes managing stress, controlling impulses, motivating oneself, and setting and working toward achieving personal and academic goals.	CRP3. Attend to personal health and financial well-being. **X** CRP6. Demonstrate creativity and innovation. **X** CRP8. Utilize critical thinking to make sense of problems and persevere in solving them. CRP11. Use technology to enhance productivity.
Social awareness: The ability to take the perspective of and empathize with others from diverse backgrounds and cultures, to understand social and ethical norms for behavior, and to recognize family, school, and community resources and supports.	CRP1. Act as a responsible and contributing citizen and employee. CRP9. Model integrity, ethical leadership, and effective management.
Relationship skills: The ability to establish and maintain healthy and rewarding relationships with diverse individuals and groups. This includes communicating clearly, listening actively, cooperating, resisting inappropriate social pressure, negotiating conflict constructively, and seeking and offering help when needed.	**X** CRP4. Communicate clearly and effectively and with reason. CRP9. Model integrity, ethical leadership, and effective management. CRP12. Work productively in teams while using cultural global competence.
Responsible decision making: The ability to make constructive and respectful choices about personal behavior and social interactions based on consideration of ethical standards, safety concerns, social norms, the realistic evaluation of consequences of various actions, and the well-being of self and others.	CRP5. Consider the environmental, social, and economic impact of decisions. CRP7. Employ valid and reliable research strategies. **X** CRP8. Utilize critical thinking to make sense of problems and persevere in solving them. CRP9. Model integrity, ethical leadership, and effective management.

Standard 9: 21st Century Life and Careers		
9.1: Personal Financial Literacy: *This standard outlines the important fiscal knowledge, habits, and skills that must be mastered in order for students to make informed decisions about personal finance. Financial literacy is an integral component of a student's college and career readiness, enabling students to achieve fulfilling, financially-secure, and successful careers.*	**9.2: Career Awareness, Exploration & Preparation:** *This standard outlines the importance of being knowledgeable about one's interests and talents, and being well informed about postsecondary and career options, career planning, and career requirements.*	**9.3: Career and Technical Education:** *This standard outlines what students should know and be able to do upon completion of a CTE Program of Study.*
A. Income and Careers B. Money Management C. Credit and Debt Management D. Planning, Saving, and Investing E. Becoming a Critical Consumer F. Civic Financial Responsibility G. Insuring and Protecting	A. Career Awareness (K-4) B. Career Exploration (5-8) **X** C. Career Preparation (9-12)	A. Agriculture, Food & Natural Res. **X** B. Architecture & Construction C. Arts, A/V Technology & Comm. D. Business Management & Admin. E. Education & Training F. Finance G. Government & Public Admin. H. Health Science I. Hospital & Tourism J. Human Services K. Information Technology L. Law, Public, Safety, Corrections & Security M. Manufacturing N. Marketing **X** O. Science, Technology, Engineering & Math P. Transportation, Distribution & Log.

Course Materials	
Core Instructional Materials: *These are the board adopted and approved materials to support the curriculum, instruction, and assessment of this course.*	**Differentiated Resources**: *These are teacher and department found materials, and also approved support materials that facilitate differentiation of curriculum, instruction, and assessment of this course.*
• Walker, Jearl, et al. *Fundamentals of Physics*. 9th ed., vol 1, John Wiley & Sons, 2011 • Jewett,John W. *Principles of Physics: A Calculus-based Text*. 4th ed., Thomson/Brooks/Cole, 2006	• Applicable YouTube videos • Applicable online physics applets • Applicable PhET applications (University of Colorado) • Ranking Tasks in Physics

AP Physics C: Mechanics

Unit Title / Topic: Calculus	Unit Duration: 16 class periods

Stage 1: Desired Results

Established Goals:

The calculus curriculum is not explicitly stated within the College Board course description of AP Physics C: Mechanics, only that students must use differential and integral calculus within the AP Physics C: Mechanics course. The following topics listed under "Students will know" are all used in order to complete the AP Physics C: Mechanics curriculum, with the exception of "chain rule", which exists as a stepping stone concept to better explain "u-substitution".

Transfer Goal:

Students will be able to independently use their learning to…

- Complete AP Physics C: Mechanics.

Students will understand that:	Essential Questions:
● Calculus is the language of physics ● Derivatives measure instantaneous rates of change between two variables ● Integrals are an infinite sum of infinitesimal products of two variables. ● Differential equations relate a variable to its own derivative.	● How are slopes of nonlinear functions computed? ● How are areas of curves computed?

Students will know:	Students will be able to:
● Derivatives ● Definite integrals ● Indefinite integrals ● Chain rule ● U-substitution ● Differential equations ● Separation of variables	● Compute derivatives of polynomial, trigonometric, exponential, and logarithmic functions ● Compute definite and indefinite integrals of polynomial, trigonometric, exponential, and logarithmic functions ● Compute derivatives of composite functions through the "chain rule" ● Compute definite and indefinite integrals of composite functions through "u-substitution" ● Solve ordinary differential equations through the method of separations of variables.

Stage 2: Acceptable Evidence

Transfer Task

The entirety of the *AP Physics C: Mechanics* course is the transfer task of this unit.

AP Physics C: Mechanics

Unit Title / Topic: Kinematics	Unit Duration: 13 class periods

Stage 1: Desired Results

Established Goals:

Objective A.1.A.1: Given a graph of one of the kinematic quantities, position, velocity, or acceleration, as a function of time, they can recognize in what time intervals the other two are positive, negative, or zero, and can identify or sketch a graph of each as a function of time.

Objective A.1.A.2: Given an expression for one of the kinematic quantities, position, velocity, or acceleration, as a function of time, they can determine the other two as a function of time, and find when these quantities are zero or achieve their maximum and minimum values.

Objective A.1.B.1: Write down expressions for velocity and position as function of time and identify or sketch graphs of these quantities

Objective A.1.B.2: Use the equations $v_x = v_{x0} + a_x t$, $x = x_0 + v_{x0}t + ½\, a_x t^2$, and $v_x^{\,2} = v_{x0}^{\,2} + 2a_x(x\text{-}x_0)$ to solve problems involving one-dimensional motion with constant acceleration.

Objective A.1.C.1: Students should know how to deal with situations in which acceleration is a specified function of velocity and time so they can write an appropriate differential equation and solve it for $v(t)$ by separation of variables incorporating correctly a given initial value of v.

Objective A.2.A.1: Determine components of a vector along two specified, mutually perpendicular axes.

Objective A.2.A.2: Determine the net displacement of a particle or the location of a particle relative to another.

Objective A.2.A.3: Determine the change in velocity of a particle of the velocity of one particle relative to another.

Objective A.2.B.1: Students should understand the general motion of a particle in two dimensions so that, given function $x(t)$ and $y(t)$ which describe this motion, they can determine the components, magnitude and direction of the particle's velocity and acceleration as functions of time.

Objective A.2.C.1: Write down expressions for the horizontal and vertical components of velocity and position as functions of time, and sketch or identify graphs of these components.

Objective A.2.C.2: Use these expression in analyzing the motion of a projectile that is projected with an arbitrary initial velocity.

Transfer Goal:

Students will be able to <u>independently</u> use their learning to…

- Predict the impact location of a projectile using parametric equations and Google Sheets to model the equations

Students will understand that:

- The kinematic quantities are related to each other through calculus operations.
- Coordinates in a Cartesian plane, such as x and y, can themselves be functions of a third parameter.

Essential Questions:

- How do I address non-constant accelerations?
- Can certain approaches/concepts be combined to solve problems?

Students will know:

- The derivative-integral cycle for kinematic quantities
- Vector calculus (basic)
- Parametric equations

Students will be able to:

- Given one graph of position vs time, velocity vs time, or acceleration vs time, construct the other two graphs.
- Given one of position, velocity, or acceleration as a function of time, perform differential or integral calculus as needed to determine the other two functions.
- Derive a set of kinematic equations for any given acceleration that is a function of time.
- Perform differential and integral calculus to position, velocity, and acceleration vectors.
- Given horizontal and vertical position as functions of time, $x(t)$ and $y(t)$, construct the function $y(x)$ via substitution.

Stage 2: Acceptable Evidence

Transfer Task

Students will be given a projectile launcher of known launch speed and a steel ball. The students will need to use parametric equations to model the trajectory of a projectile in a two-dimensional plane in order to determine the landing location. Targets will be placed on horizontal and vertical surfaces throughout the room for students to try to hit. Computer software such as Google Sheets may be used to help students determine the optimal launch height, angle, distance, etc.

AP Physics C: Mechanics

Unit Title / Topic: Newton's Laws of Motion	Unit Duration: 13 class periods

Stage 1: Desired Results

Established Goals:

Objective B.1.A.1: Students should be able to analyze situations in which a particle remains at rest, or moves with constant velocity, under the influence of several forces.
Objective B.2.A.1: Calculate, for an object moving in one dimension, the velocity change that results when a constant force F acts over a specified time interval.
Objective B.2.A.2: Calculate, for an object moving in one dimension, the velocity change that results when a force $F(t)$ acts over a specified time interval.
Objective B.2.A.3: Determine for an object moving in a plane whose velocity vector undergoes a specified change over a specified time interval, the average force that acted on the object.
Objective B.2.B.1: Draw a well-labeled, free-body diagram showing all real forces that act on the object.
Objective B.2.B.2: Write down the vector equation that results from applying Newton's second law to the object, and take the components of this equation along appropriate axes.
Objective B.2.C.1: Students should be able to 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 force that makes up the net force, such as motion up or down with constant acceleration.
Objective B.2.D.1: Write down the relationship between the normal and frictional forces on a surface.
Objective B.2.D.2: Analyze situations in which an object moves along a rough inclined plane or horizontal surface.
Objective B.2.D.3: Analyze under what circumstances an object will start to slip, or to calculate the magnitude of the force of static friction.
Objective B.2.E.1: Find the terminal velocity of an object moving vertically under the influence of a retarding force dependent upon velocity.
Objective B.2.E.2: Describe qualitatively, with the aid of graphs, the acceleration, velocity, and displacement of such a particle when it is released from rest or is projected vertically with specified initial velocity.
Objective B.2.E.3: Use Newton's second law to write a differential equation for the velocity of the object as a function of time.
Objective B.2.E.4: Use the method of separation of variables to derive the equation for the velocity as a function of time from the differential equation that follows from Newton's second law.
Objective B.2.E.5: Derive an expression for the acceleration as a function of time for an object falling under the influence of drag forces.
Objective B.3.A.1: Students should understand Newton's third law so that, for a given system, they can identify the force pairs and the objects on which the act, and state the magnitude and direction of each force.
Objective B.3.B.1: Students should be able to apply Newton's third law in analyzing the force of contact between two objects that accelerate together along a horizontal or vertical line, or between two surfaces that slide across one another.
Objective B.3.C.1: Students should know that the tension is constant in a light string that passes over a massless pulley and should be able to use this fact in analyzing the motion of a system of two objects joined by a string.
Objective B.3.D.1: Students should be able to solve problems in which applications of Newton's laws leads to two or three simultaneous linear equations involving unknown forces are accelerations.

Transfer Goal:

Students will be able to independently use their learning to…

- Analyze a set of trajectories of one object subject to air resistance and determine the terminal velocity and differential equation(s) that govern them.

Students will understand that:	Essential Questions:
• A mathematical equation is not needed in order to sketch graphs. • There are upper limits to accelerations and velocities.	• How do I address non-constant forces? • Can certain approaches/concepts be combined to solve problems?

Students will know:	Students will be able to:
• Acceleration as a function of time is analogous to force as a function of time. • How to use Newton's third law to establish mathematical relationships for use with $F=ma$. • There is a maximum acceleration for an object that is slipping. • Air resistance is a function of velocity	• Determine the equations of motion of an object as a result of constant and non-constant forces. • Determine the point of slipping when one object is at rest on top of another. • Calculate the terminal velocity of an object using Newton's laws and limits • Calculate the velocity of an object in the presence of air resistance as a function of time using differential equations. • Sketch graphs of position, velocity, and acceleration as functions of time with and without the aid of equations. • Use Newton's third law to analyze internal contact forces in systems of particles/objects.

Stage 2: Acceptable Evidence

Transfer Task

Students will be given coordinates for vertical position as a function of time for three separate trajectories of the same object. From these three sets of 25 data points each students must, using concepts of limits and calculus, determine quantities such as the terminal velocity of the object, initial launch speed and direction of each trajectory, graphs of velocity and acceleration vs time, equations $x(t)$, $v(t)$, and $a(t)$, and the differential equations that govern each trajectory.

AP Physics C: Mechanics

Unit Title / Topic: Work, Energy, Power	Unit Duration: 13 class periods

Stage 1: Desired Results

Established Goals:

Objective C.1.A.1: Calculate the work done by a specified constant force on an object that undergoes a specific displacement.
Objective C.1.A.2: Relate the work done by a specific force to the area under a graph of force as a function of position, and calculate this work in the case where the force is a linear function of position.
Objective C.1.A.3: Use integration to calculate the work performed by a force $F(x)$ on an object that undergoes a specific displacement in one dimension.
Objective C.1.A.4: Use the scalar product operation to calculate the work performed by a specified constant force $\boldsymbol{F}$ on an object that undergoes a displacement in a plane.
Objective C.1.B.1: Calculate the change in kinetic energy or speed that results from performing a specified amount of work on an object.
Objective C.1.B.2: Calculate the work performed by the net force, or by each of the forces that make up the net force, on an object that undergoes a specified change in speed of kinetic energy.
Objective C.1.B.3: Apply the theorem to determine the change in an object's kinetic energy and speed that result from the application of specified forces or to determine the force that is required in order to bring an object to rest in a specified distance.
Objective C.2.A.1: State alternative definitions of "conservative force" and explain why these definitions are equivalent.
Objective C.2.A.2: Describe examples of conservative forces and non-conservative forces.
Objective C.2.B.1: State the general relation between force and potential energy and explain why potential energy can be associated only with conservative forces..
Objective C.2.B.2: Calculate the potential energy function associated with a specified one-dimensional force $F(x)$.
Objective C.2.B.3: Calculate the magnitude and direction of a one-dimensional force when give the potential energy function $U(x)$ for the force.
Objective C.2.B.4: Write an expression for the force exerted by an ideal spring and for the potential energy of a stretched or compressed spring.
Objective C.2.B.5: Calculate the potential energy of one or more objects in a uniform gravitational field.
Objective C.3.A.1: State and apply the relation between the work performed on an object by non-conservative forces and the change in an object's mechanical energy.
Objective C.3.A.2: Describe and identify situations in which mechanical energy is converted to other forms of energy.
Objective C.3.A.3: Analyze situations in which an object's mechanical energy is changed by friction or by a specified externally applied force.
Objective C.3.B.1: Identify situations in which mechanical energy is or is not conserved.
Objective C.3.B.2: Apply conservation of energy in analyzing the motion of systems of connected objects such as an Atwood's machine.
Objective C.3.B.3: Apply conservation of energy in analyzing the motion of objects that move under the influence of springs.
Objective C.3.B.4: Apply conservation of energy in analyzing the motion of objects that move under the influence of other non-conservative forces.
Objective C.3.C.1: Students should be able to recognize and solve problems that call for application of both conservation of energy and Newton's laws.
Objective C.4.A.1: Calculate the power required to maintain the motion of an object with constant acceleration (e.g., to move an object along a level surface, to raise an object at a constant rate, or to overcome friction for an object that is moving at constant speed).
Objective C.4.B.1: Calculate the work performed by a force that supplies constant power, or the average power supplied by a force that performs a specified amount of work.

Transfer Goal:

Students will be able to independently use their learning to…

- Analyze the nonlinearity of a rubber band and identify the region of elastic deformation, the region of plastic deformation, the elastic limit, and point of failure.

Students will understand that:

- Some quantities in physics have multiple, equivalent mathematical definitions.
- Newton's laws and the conservation of energy are not mutually exclusive.
- Not all restoring forces are Hookean.

Essential Questions:

- How do I address non-constant forces?
- Can certain approaches/concepts be combined to solve problems?

Students will know:

- Work is the integral of force with respect to position.
- Work is the dot product between force and position.
- All conservative forces have an associated potential energy function.
- Not all springs obey Hooke's law
- Though normally one can choose to solve a problem with either Newton's laws or the conservation of energy, some problems require the use of both to solve.

Students will be able to:

- Calculate the work done by constant and non-constant forces as function of position.
- Calculate the potential energy as a function of position of a conservative force.
- Calculate the magnitude and direction of a conservative force given the force's potential energy function.
- Apply the conservation of energy to systems of multiple connected pieces.
- Determine if the conservation of energy may or may not be used.
- Calculate the work done by nonlinear springs
- Use Newton's laws and the conservation of energy together to solve problems
- Calculate the power required to sustain a given velocity and the work done by that force.

Stage 2: Acceptable Evidence

Transfer Task

Students will be given a rubber band, a ring stand, and a set of masses. Students will slowly add mass to the bottom of the rubber band, stretching it, and recording the restoring force of the spring vs the displacement from equilibrium of the rubber band. Students will record many data points and build a full profile of F vs x. Using Software such as Google sheets to help analyze the data, students will determine the equation that best fits the nonlinearity of the rubber band, and identify key features of their data (region of elastic deformation, region of plastic deformation, the elastic limit, and point of failure).

AP Physics C: Mechanics

Unit Title / Topic: Linear Momentum	Unit Duration: 13 class periods

Stage 1: Desired Results

Established Goals:

Objective D.1.A.1: Identify by inspection the center of mass of a symmetrical object.
Objective D.1.A.2: Locate the center of mass of a system consisting of two such objects.
Objective D.1.A.3: Use integration to find the center of mass of a thin rod of non-uniform density
Objective D.1.B.1: Students should be able to understand and apply the relation between center-of-mass velocity and linear momentum, and between center-of-mass acceleration and net external force for a system of particles.
Objective D.1.C.1: Students should be able to define center of gravity and use this concept to express the gravitational potential energy of a rigid object in terms of the position of its center of mass.
Objective D.2.A.1: Relate mass, velocity, and linear momentum for a moving object, and calculate the total linear momentum of a system of objects.
Objective D.2.B.1: Relate impulse to the change in linear momentum and the average force acting on an object.
Objective D.2.C.1: State and apply the relations between linear momentum and center-of-mass motion for a system of particles.
Objective D.2.D.1: Calculate the area under a force versus time graph and relate it to the change in momentum of an object.
Objective D.2.E.1: Calculate The change in momentum of an object given a function $F(t)$ for the net force acting on the object.
Objective D.3.A.1: Explain how linear momentum conservation follows as a consequence of Newton's third law for an isolated system.
Objective D.3.A.2: Identify situations in which linear momentum, or a component of the linear momentum vector, is conserved.
Objective D.3.A.3: Apply linear momentum conservation to one-dimensional elastic and inelastic collisions and two-dimensional completely inelastic collisions.
Objective D.3.A.4: Apply linear momentum conservation to two-dimensional elastic and inelastic collisions.
Objective D.3.A.5: Analyze situations in which two or more objects are pushed apart by a spring or other agency, and calculate how much energy is released in such a process.
Objective D.3.B.1: Analyze the uniform motion of an object relative to a moving medium such as a flowing stream.
Objective D.3.B.2: Analyze the motion of particles relative to a frame of reference that is accelerating horizontally or vertically at a uniform rate.

Transfer Goal:

Students will be able to <u>independently</u> use their learning to…
- Calculate the coefficient of restitution of a given collision.

Students will understand that:
- Some quantities in physics have multiple, equivalent mathematical definitions.
- Objects with non-constant mass are still subject to the conservation of momentum.
- F=ma is a special form of Newton's second law

Essential Questions:
- How do I address non-constant forces?
- How do I address non-constant density in massive objects?
- Can certain approaches/concepts be combined to solve problems?

Students will know:
- The center of mass of a system of multiple objects can be determined by treating each object as a point at its center of mass.
- Impulse is the integral of force with respect to time
- Impulse is the change in momentum
- Force is the time derivative of momentum.
- If the mass of an object varies as time progresses then so does its velocity.
- Collisions involving springs conserve momentum but do not conserve energy.

Students will be able to:
- Calculate the center of mass of constant and non-constant densities.
- Calculate the velocity and acceleration of the center of mass of an object or collection of objects.
- Calculate the velocity as a function of time for objects in a system that have variable mass.
- Use both the conservation of momentum and conservation of energy to solve elastic collision problems.
- Analyze energy loss in collisions involving springs.

Stage 2: Acceptable Evidence

Transfer Task

Students will be given multiple balls of different type (tennis ball, golf ball, "bouncy" ball, etc.) and asked to determine the coefficient of restitution which measures what percentage of energy is retained during a collision. Students will drop these different balls onto a student-determined surface and analyze the collision between each ball and the surface. Each ball surface will have a unique coefficient of restitution. Students will use their data to make predictions on how high each ball will bounce on its fifth bounce.

AP Physics C: Mechanics

Unit Title / Topic: Circular Motion and Rotation	Unit Duration: 20 class periods

Stage 1: Desired Results

Established Goals:

Objective E.1.A.1: Relate the radius of the circle and the speed or rate of revolution of the particle to the magnitude of the centripetal acceleration.
Objective E.1.B.1: Describe the direction of the particle's velocity and acceleration at any instant during the motion.
Objective E.1.C.1: Determine the components of the velocity and acceleration vectors at any instant, and sketch or identify graphs of these quantities.
Objective E.1.D.1: Motion in a horizontal circle (e.g. mass on a rotating merry-go-round, or car rounding a banked curve.
Objective E.1.D.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).
Objective E.2.A.1: Calculate the magnitude and direction of the torque associated with a given force.
Objective E.2.A.2: Calculate the torque on a rigid object due to gravity.
Objective E.2.B.1: State the conditions for translational and rotational equilibrium of a rigid object.
Objective E.2.B.2: Apply these conditions in analyzing the equilibrium of a rigid object under the combined influence of a number of coplanar forces applied at different locations.
Objective E.2.C.1: Determine by inspection which of a set of symmetrical objects of equal mass has the greatest rotational inertia.
Objective E.2.C.2: Determine by what factor an object's rotational inertia changes if all its dimension are increased by the same factor.
Objective E.2.D.1: Determine the rotational inertia of a collection of point masses lying in a plane about an axis perpendicular to the plane.
Objective E.2.D.2: Determine the rotational inertia of a thin rod of uniform density about an arbitrary axis perpendicular to the rod.
Objective E.2.D.3: Determine the rotational inertia of a thin cylindrical shell about its axis, or an object that may be viewed as being made up of coaxial shells.
Objective E.3.A.1: Students should understand the analogy between translational and rotational kinematics so they can write and apply relations among the angular acceleration, angular velocity, and angular displacement of an object that rotates about a fixed axis with constant angular acceleration.
Objective E.3.B.1: Students should be able to use the right-hand rule to associate an angular velocity vector with a rotating object.
Objective E.3.C.1: Describe in detail the analogy between fixed-axis rotation and straight-line translation.
Objective E.3.C.2: Determine the angular acceleration with which a rigid object is accelerated about a fixed axis when subjected to a specified external torque or force.
Objective E.3.C.3: Determine the radial and tangential acceleration of a point on a rigid object.
Objective E.3.C.4: Apply conservation of energy to problems of fixed-axis rotation.
Objective E.3.C.5: Analyze problems involving strings and massive pulleys.
Objective E.3.D.1: Write down, justify, and apply the relation between linear and angular velocity or between linear and angular acceleration, for an object of circular cross-section that rolls without slipping along a fixed plane, and determine the velocity and acceleration of an arbitrary point on such an object.
Objective E.3.D.2: Apply the equations of translational and rotational motion simultaneously in analyzing rolling with slipping.
Objective E.3.D.3: Calculate the total kinetic energy of an object that is undergoing both translational and rotational motion, and apply energy conservation in analyzing such motion.
Objective E.4.A.1: Calculate the torque of a specified force about an arbitrary origin
Objective E.4.A.2: Calculate the angular momentum vector for a moving particle.
Objective E.4.A.3: Calculate the angular momentum vector for a rotating rigid object in simple cases where this vector lies parallel to the angular velocity vector.
Objective E.4.B.1: Recognize the conditions under which the law of conservation is applicable and relate this law to one- and two-particle systems such as satellite orbits.
Objective E.4.B.2: State the relation between net external torque and angular momentum, and identify situations in which angular momentum is conserved.
Objective E.4.B.3: Analyze the problems in which the moment of inertia of an object changed as it rotates freely about a fixed axis.
Objective E.4.B.4: Analyze a collision between a moving particle and a rigid object that can rotate about a fixed axis.

Transfer Goal:

Students will be able to independently use their learning to…

- Make a mechanical model of a human bicep and linearize it to determine the important variables for muscle efficiency in the human body.

Students will understand that:

- A vector can change even if its magnitude is constant.
- Rolling and slipping are not mutually exclusive.
- Every translational concept has an analogous rotational equivalent.

Essential Questions:

- How do I address non-constant forces?
- Can certain approaches/concepts be combined to solve problems?

Students will know:

- The direction of velocity and acceleration are always changing in rotational motion, even if the magnitude remains the same.
- Moment of inertia formulae are derived through integration.
- Rolling and slipping can be combined by solving rotational and translational kinematic equations simultaneously in a system of equations.
- How to combine rotational and translational approaches into the same problem
- How to combine rolling and slipping into the same problem.

Students will be able to:

- Determine the magnitude and direction of velocity and acceleration vectors in circular motion as well as their components.
- Solve problems involving both vertical and horizontal loops.
- Solve problems that use both linear and rotational motion together.
- Derive the moment of inertia of uniform rods and cylinders.
- Conceptually differentiate between high and low moments of inertia.
- Solve problems that combine rolling and slipping.
- Solve problems involving massive pulleys.
- Conserve angular momentum in problems that contain pure rotational as well as a combination of rotation and translation.

Stage 2: Acceptable Evidence

Transfer Task

Students will be given materials with which to construct a model of a human bicep with different "attachment locations" along the "forearm" to vary the distance from the fulcrum and the angle of the muscle. Students will use a spring scale to measure the force exerted by the "bicep" for different attachment locations along the forearm. Students will linearize this data in order to determine which variables and what powers are important. Students will also compare the force exerted by the forearm to the weight of the forearm itself.

AP Physics C: Mechanics

Unit Title / Topic: Oscillations and Gravitation	Unit Duration: 20 class periods

Stage 1: Desired Results

Established Goals:

Objective F.1.A.1: Sketch or identify a graph of displacement as a function of time, and determine from such a graph the amplitude, period and frequency of the motion.
Objective F.1.B.1: Write down an appropriate expression for displacement of the form $Asin(wt)$ or $Acos(wt)$ to describe the motion.
Objective F.1.C.1: Find an expression for the velocity as a function of time.
Objective F.1.D.1: State the relations between acceleration, velocity and displacement, and identify points in the motion where these quantities are zero or achieve their greatest positive and negative values.
Objective F.1.E.1: State and apply the relation between frequency and period.
Objective F.1.F.1: Recognize that a system that obeys a differential equation of the form $d^2x/dt^2 = -w^2x$ must execute simple harmonic motion, and determine the frequency and period of such motion.
Objective F.1.G.1: State how the total energy of an oscillating system depends on the amplitude of the motion,sketch of identify a graph of kinetic or potential energy as a function of time, and identify points in the motion where this energy is all potential or all kinetic.
Objective F.1.H.1: Calculate the kinetic and potential energies of an oscillating system as functions of time, sketch or identify graphs of these functions, and prove that he sum of kinetic and potential energy is constant.
Objective F.1.I.1: Calculate the maximum displacement or velocity of a particle that moves in simple harmonic motion with specified initial position and velocity.
Objective F.1.J.1: Develop a qualitative understanding of resonance so they can identify situations in which a system will resonate in response to a sinusoidal external force.
Objective F.2.A.1: Derive the expression for the period of oscillation of a mass on a spring.
Objective F.2.B.1: Apply the expression for the period of oscillation of a mass on a spring.
Objective F.2.C.1: Analyze problems in which a mass hangs from a spring and oscillates vertically.
Objective F.2.D.1: Analyze problems in which a mass attached to a spring oscillates horizontally.
Objective F.2.E.1: Determine the period of oscillation for systems involving series or parallel combinations of identical springs, or springs of differing lengths.
Objective F.3.A.1: Derive the expression for the period of a simple pendulum.
Objective F.3.B.1: Apply the expression for the period of a simple pendulum.
Objective F.3.C.1: State what approximation must be made in deriving the period.
Objective F.3.D.1: Analyze the motion of a torsional pendulum or physical pendulum in order to determine the period of small oscillations
Objective F.4.A.1: Determine the force that one spherically symmetrical mass exerts on another.
Objective F.4.B.1: Determine the strength of the gravitational field at a specified point outside a spherically symmetrical mass.
Objective F.4.C.1: Describe the gravitational force inside and outside a uniform sphere, and calculate how the field at the surface depends on the radius and density of the sphere.
Objective F.5.A.1: For a circular orbit recognize that the motion does not depend on the object's mass; describe qualitatively how the velocity, period of revolution and centripetal acceleration depend upon the radius of the orbit; and derive the expressions for the velocity and period of revolution in such an orbit.
Objective F.5.A.2: Derive Kepler's third law for the case of circular orbits.
Objective F.5.A.3: Derive and apply the relations among kinetic energy, potential energy and total energy for such an orbit.
Objective F.5.B.1: State Kepler's three laws of planetary motion and use them to describe in qualitative terms the motion of an object in an elliptical orbit.
Objective F.5.B.2: Apply conservation of angular momentum to determine the velocity and radial distance at any point in the orbit.
Objective F.5.B.3: Apply angular momentum conservation and energy conservation to relate the speeds of an object at the two extremes of an elliptical orbit.
Objective F.5.B.4: Apply energy conservation in analyzing the motion of an object that is projected straight up from a planet's surface of that is projected directly toward the planet from far above the surface.

Transfer Goal:

Students will be able to <u>independently</u> use their learning to…

- Analyze the motion of a physical pendulum.

Students will understand that:

- Different types of motion are governed by different differential equations.
- Newton's laws and Kepler's laws are not mutually exclusive.

Essential Questions:

- How can I address non-constant forces?
- Can certain approaches/concepts be combined to solve problems?

Students will know:

- Locations of maxima, minima, and zeros of graphs of position, velocity, and acceleration as function of time.
- The equation $d^2x/dt^2 = -w^2x$ describes simple harmonic motion.
- Small angle approximation for oscillations.
- The force of gravity within a massive body is different than the force of gravity outside of a massive body.
- How to combine Newton's laws and Kepler's laws together.
- Kepler's second law is equivalent to the conservation of angular momentum for planets.

Students will be able to:

- Analyze graphs of position, velocity, and acceleration as functions of time for objects exhibiting simple harmonic motion and the equations that represent them.
- Solve differential equations that describe simple harmonic motion.
- Solve problems involving -mass spring systems in horizontal and vertical oscillations.
- Solve problems involving simple pendulums.
- Solve problems involving physical and torsional pendulums.
- Explore the force of gravity inside and outside of solid, massive spheres.
- Use Kepler's laws and Newton's law of universal gravitation to describe the orbital speed and orbital period of planetary orbits.
- Use the conservation of angular momentum to compare the speed of an orbiting body at one location in its orbit to the speed at another location in its orbit.

Stage 2: Acceptable Evidence

Transfer Task

Students will be given a meter stick with holes drilled into it. Students will record the period of oscillation of the physical pendulum when the pendulum oscillation about different points and plot the data. Students will then apply differential calculus to determine the location from the pendulum's center of mass that the period is minimized.