CURRICULUM

FOR

AP PHYSICS

GRADES 11-12

This curriculum is part of the Educational Program of Studies of the Rahway Public Schools.

ACKNOWLEDGMENTS

Dr. Susan Dube, Program Supervisor of Science/Technology Education

The Board acknowledges the following who contributed to the preparation of this curriculum.

Dr. Susan Dube

Dr. Tiffany Beer, Director of Curriculum Instruction

Subject/Course Title:
AP Physics
Grades 11-12

Date of Board Adoptions:
September 21, 2021

PACING GUIDE

Unit	**Title**	**Pacing**
1	Kinematics	6 weeks
2	Dynamics	6 weeks
3	Circular Motion and Gravitation	6 weeks
4	Energy	6 weeks
5	Momentum	5 weeks
6	Simple Harmonic Motion	5 weeks
7	Torque and Rotational Motion	6 weeks

ACCOMMODATIONS

504 Accommodations:

- Provide scaffolded vocabulary and vocabulary lists.
- Provide extra visual and verbal cues and prompts.
- Provide adapted/alternate/excerpted versions of the text and/or modified supplementary materials.
- Provide links to audio files and utilize video clips.
- Provide graphic organizers and/or checklists.
- Provide modified rubrics.
- Provide a copy of teaching notes, especially any key terms, in advance.
- Allow additional time to complete assignments and/or assessments.
- Provide shorter writing assignments.
- Provide sentence starters.
- Utilize small group instruction.
- Utilize Think-Pair-Share structure.
- Check for understanding frequently.
- Have student restate information.
- Support auditory presentations with visuals.
- Weekly home-school communication tools (notebook, daily log, phone calls or email messages).
- Provide study sheets and teacher outlines prior to assessments.
- Quiet corner or room to calm down and relax when anxious.
- Reduction of distractions.
- Permit answers to be dictated.
- Hands-on activities.
- Use of manipulatives.
- Assign preferential seating.
- No penalty for spelling errors or sloppy handwriting.
- Follow a routine/schedule.
- Provide student with rest breaks.
- Use verbal and visual cues regarding directions and staying on task.
- Assist in maintaining agenda book.

IEP Accommodations:

- Provide scaffolded vocabulary and vocabulary lists.
- Differentiate reading levels of texts (e.g., Newsela).
- Provide adapted/alternate/excerpted versions of the text and/or modified supplementary materials.
- Provide extra visual and verbal cues and prompts.
- Provide links to audio files and utilize video clips.
- Provide graphic organizers and/or checklists.
- Provide modified rubrics.
- Provide a copy of teaching notes, especially any key terms, in advance.
- Provide students with additional information to supplement notes.
- Modify questioning techniques and provide a reduced number of questions or items on tests.
- Allow additional time to complete assignments and/or assessments.
- Provide shorter writing assignments.
- Provide sentence starters.
- Utilize small group instruction.
- Utilize Think-Pair-Share structure.
- Check for understanding frequently.
- Have student restate information.
- Support auditory presentations with visuals.
- Provide study sheets and teacher outlines prior to assessments.
- Use of manipulatives.
- Have students work with partners or in groups for reading, presentations, assignments, and analyses.
- Assign appropriate roles in collaborative work.
- Assign preferential seating.
- Follow a routine/schedule.

Gifted and Talented Accommodations:

- Differentiate reading levels of texts (e.g., Newsela).
- Offer students additional texts with higher lexile levels.
- Provide more challenging and/or more supplemental readings and/or activities to deepen understanding.
- Allow for independent reading, research, and projects.
- Accelerate or compact the curriculum.
- Offer higher-level thinking questions for deeper analysis.
- Offer more rigorous materials/tasks/prompts.
- Increase number and complexity of sources.
- Assign group research and presentations to teach the class.
- Assign/allow for leadership roles during collaborative work and in other learning activities.

ELL Accommodations:

- Provide extended time.
- Assign preferential seating.
- Assign peer buddy who the student can work with.
- Check for understanding frequently.
- Provide language feedback often (such as grammar errors, tenses, subject-verb agreements, etc…).
- Have student repeat directions.
- Make vocabulary words available during classwork and exams.
- Use study guides/checklists to organize information.
- Repeat directions.
- Increase one-on-one conferencing.
- Allow student to listen to an audio version of the text.
- Give directions in small, distinct steps.
- Allow copying from paper/book.
- Give student a copy of the class notes.
- Provide written and oral instructions.
- Differentiate reading levels of texts (e.g., Newsela).

	• Shorten assignments. • Read directions aloud to student. • Give oral clues or prompts. • Record or type assignments. • Adapt worksheets/packets. • Create alternate assignments. • Have student enter written assignments in criterion, where they can use the planning maps to help get them started and receive feedback after it is submitted. • Allow student to resubmit assignments. • Use small group instruction. • Simplify language. • Provide scaffolded vocabulary and vocabulary lists. • Demonstrate concepts possibly through the use of visuals. • Use manipulatives. • Emphasize critical information by highlighting it for the student. • Use graphic organizers. • Pre-teach or pre-view vocabulary. • Provide student with a list of prompts or sentence starters that they can use when completing a written assignment. • Provide audio versions of the textbooks. • Highlight textbooks/study guides. • Use supplementary materials. • Give assistance in note taking • Use adapted/modified textbooks. • Allow use of computer/word processor. • Allow student to answer orally, give extended time (time-and-a-half). • Allow tests to be given in a separate location (with the ESL teacher). • Allow additional time to complete assignments and/or assessments. • Read question to student to clarify. • Provide a definition or synonym for words on a test that do not impact the validity of the exam. • Modify the format of assessments. • Shorten test length or require only selected test items. • Create alternative assessments. • On an exam other than a spelling test, don’t take points off for spelling errors.

RAHWAY PUBLIC SCHOOLS CURRICULUM

UNIT OVERVIEW

Content Area: Physics

Unit Title: Kinematics

Target Course/Grade Level: 11-12

Unit Summary: This unit of study is based on the interactions of an object with other objects can be described by forces. The world is in a constant state of motion. To understand the world, students must first understand movement. By studying kinematics, students will learn to represent motion—both uniform and accelerating—in narrative, graphical, and/or mathematical forms and from different frames of reference. These representations will help students analyze the specific motion of objects and systems while also dispelling some common misconceptions they may have about motion, such as exclusively using negative acceleration to describe an object slowing down. Additionally, students will have the opportunity to go beyond their traditional understanding of mathematics. Instead of solving equations, students will use them to support their reasoning and tighten their grasp on the laws of physics. Lastly, students will begin making predictions about motion and justifying claims with evidence by exploring the relationships between the physical quantities of acceleration, velocity, position, and time. This is an important starting point for students, as these fundamental science practices will spiral throughout the course and appear in multiple units.

Approximate Length of Unit: 6 weeks

LEARNING TARGETS

Learning Standards Addressed:
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 motion of the center of mass of a system. **[SP 1.4, 2.2]**

Science Practices:

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems

• **SP 1.1** The student can create representations and models of natural or manmade phenomena and systems in the domain**.**

• **SP 1.2** The student can describe representations and models of natural or manmade phenomena and systems in the domain.
• **SP 1.3** The student can refine representations and models of natural or manmade phenomena and systems in the domain.
• **SP 1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
• **SP 1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain.

Science Practice 2: The student can use mathematics appropriately

• **SP 2.1** The student can justify the selection of a mathematical routine to solve problems.
• **SP 2.2** The student can apply mathematical routines to quantities that describe natural phenomena.
• **SP 2.3** The student can estimate numerically quantities that describe natural phenomena.

Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course

• **SP 3.1** The student can pose scientific questions.
• **SP 3.2** The student can refine scientific questions.
• **SP 3.3** The student can evaluate scientific questions.

Science Practice 4: The student can plan and implement data collection strategies in relation to a particular scientific question

• **SP 4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question.
• **SP 4.2** The student can design a plan for collecting data to answer a particular scientific question.
• **SP 4.3** The student can collect data to answer a particular scientific question.
• **SP 4.4** The student can evaluate sources of data to answer a particular scientific question.

Science Practice 5: The student can perform data analysis and evaluation of evidence

• **SP 5.1** The student can analyze data to identify patterns or relationships.
• **SP 5.2** The student can refine observations and measurements based on data analysis.
• **SP 5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

Science Practice 6: The student can work with scientific explanations and theories

• **SP 6.1** The student can justify claims with evidence.
• **SP 6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.
• **SP 6.3 T**he student can articulate the reasons that scientific explanations and theories are refined or replaced.
• **SP 6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models.
• **SP 6.5** The student can evaluate alternative scientific explanations**.**

Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains

• **SP 7.1** The student can connect phenomena and models across spatial and temporal scales.
• **SP 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.

NJ SLS Companion Standards: Reading and Writing Standards for History, Social Studies, Science, and Technical Subjects:

- **RST.9-10.1.** Accurately cite strong and thorough evidence from the text to support analysis of science and technical texts, attending to precise details for explanations or descriptions.
- **RST.9-10.2**. Determine the central ideas, themes, or conclusions of a text; trace the text’s explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

- **RST.9-10.3**. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.
- **RST.9-10.7.** Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.
- **WHST.9-10.1.** Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant sufficient textual and non-textual evidence.
  - A. Introduce precise claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that establishes clear relationships among the claim(s), counterclaims, reasons, and evidence.
- **WHST.9-10.4.** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
- **WHST.9-10.5.** Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
- **WHST.9-10.6.** Use technology, including the Internet, to produce, share, and update writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.

Interdisciplinary Connections and Standards:
Mathematics:

- **MP.2** Reason abstractly and quantitatively.
- **MP.4** Model with mathematics.
- **HSN-Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- **HSN-Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
- **HSN-Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- **HSA-SSE.A.1** Interpret expressions that represent a quantity in terms of its context.
- **HSA-SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- **HSA-CED.A.1** Create equations and inequalities in one variable and use them to solve problems.
- **HSA-CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- **HSA-CED.A.4** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- **HSF-IF.C.7** Graph functions expressed symbolically and show key features of the graph, by in hand in simple cases and using technology for more complicated cases.
- **HSS-ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots

Technology:

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.

- **Strand A.** Technology Operations and Concepts: Students demonstrate a sound understanding of technology concepts, systems and operations.
- **Strand B.** Creativity and Innovation: Students demonstrate creative thinking, construct knowledge and develop innovative products and process using technology.
- **Strand C**. Communication and Collaboration: Students use digital media and environments to communicate and work collaboratively, including at a distance, to support individual learning and contribute to the learning of others
- **Strand D**. Digital Citizenship: Students understand human, cultural, and societal issues related to technology and practice legal and ethical behavior
- **Strand E**: Research and Information Fluency: Students apply digital tools to gather, evaluate, and use information.

- **Strand F: Critical thinking, problem solving, and decision making:** Students use critical thinking skills to plan and conduct research, manage projects, solve problems, and make informed decisions using appropriate digital tools and resources.

21st Century Learning Standards:
Career Ready Practices:

- **CRP1.** Act as a responsible and contributing citizen and employee.
- **CRP2.** Apply appropriate academic and technical skills.
- **CRP4.** Communicate clearly and effectively and with reason.
- **CRP5.** Consider the environmental, social and economic impacts of decisions.
- **CRP6.** Demonstrate creativity and innovation.
- **CRP7.** Employ valid and reliable research strategies.
- **CRP8.** Utilize critical thinking to make sense of problems and persevere in solving them.
- **CRP9.** Model integrity, ethical leadership and effective management.
- **CRP11.** Use technology to enhance productivity.
- **CRP12.** Work productively in teams while using cultural global competence.

Unit Understandings
Students will understand that…

- All forces share certain common characteristics when considered by observers in inertial reference frames.
- The acceleration of the center of mass of a system is related to the net force exerted on the system.

Unit Essential Questions

- How can the motion of objects be predicted and/or explained?
- Can equations be used to answer questions regardless of the questions' specificity?
- How can the idea of frames of reference allow two people to tell the truth yet have conflicting reports?

Knowledge and Skills
Students will know…

- An observer in a reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.
  a. Displacement, velocity, and acceleration are all vector quantities.
  b. Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values. Relevant Equations: ρ Δx ρ vavg = Δt ρ Δv aavg = Δt
  c. A choice of reference frame determines the direction and the magnitude of each of these quantities.
  d. There are three fundamental interactions or forces in nature: the gravitational force, the electroweak force, and the strong force. The fundamental forces determine both the structure of objects and the motion of objects
  e. In inertial reference frames, forces are detected by their influence on the motion (specifically the velocity) of an object. So force, like velocity, is a vector quantity. A force vector has magnitude and direction. When multiple forces are exerted on an object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. The acceleration of the object is proportional to the net force.
  f. The kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included. The three kinematic equations describing linear motion with constant acceleration in one and two dimensions are vx = + vx0 a tx x = + x 2 0 vx0 t + a t 1 2 x v2 2 x = + vx0 0 2 (ax x − x)

g. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration. The kinematic equations describing angular motion with constant angular acceleration are θ θ= + t 2 0 0 ω + αt 1 2 ω ω= +0 αt ω2 2 = + ω0 0 2 (α θx −θ)
h. This also includes situations where there is both a radial and tangential acceleration for an object moving in a circular path. Relevant Equation: v2 ac = r. For uniform circular motion of radius r, v is proportional to omega, ω (for a given r), and proportional to r (for a given omega, ω). Given a radius r and a period of rotation T, students derive and apply $v = (2\pi r)/T$.

- The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.
  a. The variables *x*, *v*, and *a* all refer to the center-of-mass quantities.
- 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.
  c. The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity with time, and the center of mass velocity is equal to the rate of change of position of the center of mass with time.
  d. The variables *x*, *v*, and *a* all refer to the center-of-mass quantities.

Performance Expectations:
Students will be able to…

- re-express key elements of natural phenomena across multiple representations in the domain.
- justify the selection of a mathematical routine to solve problems.
- apply mathematical routines to quantities that describe natural phenomena.
- design a plan for collecting data to answer a particular scientific question.
- analyze data to identify patterns or relationships
- use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively
- 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]
- 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.

EVIDENCE OF LEARNING

Assessment
What evidence will be collected and deemed acceptable to show that students truly "understand"?

- Teacher observations
- Lab Reports
- **End of Unit Assessment:**
  - Students will re-express key elements of natural phenomena across multiple representations in the domain
  - Students will justify the ways in which they chose to solve problems
  - Students will determine patterns or relationships in data

Learning Activities

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

1. Meeting Point: To predict where two battery-powered cars will collide if they are released from opposite ends of the lab table at different times.
2. Match the Graph: To determine the proper placement of an air track, a glider, and a motion detector to produce a motion that matches a set of given graphs: position, velocity, and acceleration versus time.
3. Free-Fall Investigation: To determine and compare the acceleration of two objects dropped simultaneously.
4. Vector Addition: To determine the value of a resultant of several vectors, and then compare that value to the values obtained through graphical and analytical methods.
5. Shoot the Target: To determine the initial velocity of a projectile, the angle at which the maximum range can be attained, and predict where the projectile will land.
6. Chase Scenario: Lab Practicum: Students use a battery cart and a fan cart to recreate a chase scenario (police-thief) to predict the position where the 'thief' will be caught and the final speeds of both cars.

RESOURCES

Teacher Resources:

- https://apcentral.collegeboard.org/courses/resources/ap-physics-1-and-2-inquiry-based-lab-investigations?course=ap-physics-2
- https://apcentral.collegeboard.org/pdf/physics-multiple-representations-knowledge-sf.pdf?course=ap-physics-1
- https://apcentral.collegeboard.org/pdf/ap-physics-graphical-analysis.pdf?course=ap-physics-1
- https://apcentral.collegeboard.org/courses/resources/ap-physics-featured-question-projectile-concepts?course=ap-physics-2
- https://apcentral.collegeboard.org/courses/resources/ap-physics-featured-question-projectile-concepts?course=ap-physics-2
- https://apcentral.collegeboard.org/courses/resources/critical-thinking-questions-in-physics?course=ap-physics-1
- https://apcentral.collegeboard.org/courses/resources/physics-instruction-using-video-analysis-technology?course=ap-physics-1
- https://apcentral.collegeboard.org/series/teaching-strategies-limited-class-time?course=ap-physics-1

Equipment Needed:

- Laptop connection for power point presentations
- Laboratory equipment as specified for lab activities

RAHWAY PUBLIC SCHOOLS CURRICULUM

UNIT OVERVIEW

Content Area: Physics

Unit Title: Dynamics

Target Course/Grade Level: 11 - 12

Unit Summary: Students are introduced to the term force, which is the interaction of an object with another object. Part of the larger study of dynamics, forces are used as the lens through which students analyze and come to understand a variety of physical phenomena. This is accomplished by revisiting and building upon the representations presented in Unit 1, specifically the introduction to the free-body diagram. Translation, however, is key in this unit: Students must be able to portray the same object–force interactions through different graphs, diagrams, and mathematical relationships. Students will continue to make meaning from models and representations that will help them further analyze systems, the interactions between systems, and how these interactions result in change. Alongside mastering the use of specific force equations. This unit also encourages students to derive new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. The skill of making predictions will be nurtured throughout the course to help students craft sound scientific arguments.

Approximate Length of Unit: 6 weeks

LEARNING TARGETS

Learning Standards Addressed:
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 = υρ υρ 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.3.1 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]
3.A.3.2 Challenge a claim that an object can exert a force on itself. [SP 6.1]
3.A.3.3 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]
3.B.1.1 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]
3.B.1.2 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]
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]

Science Practices:

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems
- **SP 1.1** The student can create representations and models of natural or manmade phenomena and systems in the domain.
- **SP 1.2** The student can describe representations and models of natural or manmade phenomena and systems in the domain.
- **SP 1.3** The student can refine representations and models of natural or manmade phenomena and systems in the domain.
- **SP 1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
- **SP 1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain.

Science Practice 2: The student can use mathematics appropriately
- **SP 2.1** The student can justify the selection of a mathematical routine to solve problems.
- **SP 2.2** The student can apply mathematical routines to quantities that describe natural phenomena.
- **SP 2.3** The student can estimate numerically quantities that describe natural phenomena.

Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course
- **SP 3.1** The student can pose scientific questions.
- **SP 3.2** The student can refine scientific questions.
- **SP 3.3** The student can evaluate scientific questions.

Science Practice 4: The student can plan and implement data collection strategies in relation to a particular scientific question
- **SP 4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question.
- **SP 4.2** The student can design a plan for collecting data to answer a particular scientific question.
- **SP 4.3** The student can collect data to answer a particular scientific question.
- **SP 4.4** The student can evaluate sources of data to answer a particular scientific question.

Science Practice 5: The student can perform data analysis and evaluation of evidence
- **SP 5.1** The student can analyze data to identify patterns or relationships.

• **SP 5.2** The student can refine observations and measurements based on data analysis.
• **SP 5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question.
Science Practice 6: The student can work with scientific explanations and theories
• **SP 6.1** The student can justify claims with evidence.
• **SP 6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.
• **SP 6.3 T**he student can articulate the reasons that scientific explanations and theories are refined or replaced.
• **SP 6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models.
• **SP 6.5** The student can evaluate alternative scientific explanations**.**
Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains
• **SP 7.1** The student can connect phenomena and models across spatial and temporal scales.
• **SP 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.

NJ SLS Companion Standards: Reading and Writing Standards for History, Social Studies, Science, and Technical Subjects:

- **RST.9-10.1.** Accurately cite strong and thorough evidence from the text to support analysis of science and technical texts, attending to precise details for explanations or descriptions.
- **RST.9-10.2**. Determine the central ideas, themes, or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- **RST.9-10.3**. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.
- **RST.9-10.7.** Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.
- **WHST.9-10.1.** Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant sufficient textual and non-textual evidence.
    - A. Introduce precise claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that establishes clear relationships among the claim(s), counterclaims, reasons, and evidence.
- **WHST.9-10.4.** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
- **WHST.9-10.5.** Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
- **WHST.9-10.6.** Use technology, including the Internet, to produce, share, and update writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.

Interdisciplinary Connections and Standards:
Mathematics:

- **MP.2** Reason abstractly and quantitatively.
- **MP.4** Model with mathematics.
- **HSN-Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- **HSN-Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
- **HSN-Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- **HSA-SSE.A.1** Interpret expressions that represent a quantity in terms of its context.

- **HSA-SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- **HSA-CED.A.1** Create equations and inequalities in one variable and use them to solve problems.
- **HSA-CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- **HSA-CED.A.4** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- **HSF-IF.C.7** Graph functions expressed symbolically and show key features of the graph, by in hand in simple cases and using technology for more complicated cases.
- **HSS-ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots

Technology:

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.

- **Strand A. Technology Operations and Concepts:** Students demonstrate a sound understanding of technology concepts, systems and operations.
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- **Strand D**. **Digital Citizenship:** Students understand human, cultural, and societal issues related to technology and practice legal and ethical behavior
- **Strand E**: **Research and Information Fluency**: Students apply digital tools to gather, evaluate, and use information.
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21st Century Learning Standards:
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- **CRP1.** Act as a responsible and contributing citizen and employee.
- **CRP2.** Apply appropriate academic and technical skills.
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- **CRP7.** Employ valid and reliable research strategies.
- **CRP8.** Utilize critical thinking to make sense of problems and persevere in solving them.
- **CRP9.** Model integrity, ethical leadership and effective management.
- **CRP11.** Use technology to enhance productivity.
- **CRP12.** Work productively in teams while using cultural global competence.

Unit Understandings
Students will understand that…

- A system is an object or a collection of objects. Objects are treated as having no internal structure.
    - 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.
    - Some elementary particles are fundamental particles, (e.g., electrons). Protons and neutrons are composed of fundamental particles (i.e., quarks) and might be treated as either systems or objects, depending on the question being addressed.

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

- 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]

- Systems have properties that are determined by the properties and interactions of their constituent atomic and molecular substructures.
- A gravitational field υ g ρ 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.
  - On Earth, this gravitational force is called weight.
  - The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force.
  - If the gravitational force is the only force exerted on the object, the observed freefall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in Newtons/kilogram) at that location. Relevant Equation: υρ F υρ g = g m

- A system is an object or a collection of objects. Objects are treated as having no internal structure.
- 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.
- Some elementary particles are fundamental particles, (e.g., electrons). Protons and neutrons are composed of fundamental particles (i.e., quarks) and might be treated as either systems or objects, depending on the question being addressed.
- The electric charges on neutrons and protons result from their quark compositions.
- Contact forces result from the interaction of one object touching another object, and they arise from interatomic electric forces. These forces include tension, friction, normal, spring (Physics 1), and buoyant (Physics 2).
- Inertial mass is the property of an object or system that determines how its motion changes when it interacts with other objects or systems.
- Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
- Forces are described by vectors. a. Forces are detected by their influence on the motion of an object. b. Forces have magnitude and direction.
- 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.
- 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.
- If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.
- The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. The variables x, v, and a all refer to the center-of-mass quantities.
- 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.

  - The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity with time, and the center of mass velocity is equal to the rate of change of position of the center of mass with time.
  - d. The variables x, v, and a all refer to the center-of-mass quantities.
- Forces that the 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.
- 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 were extracted from its environment and the interactions with the environment were 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.
  - d. Free-body or force diagrams may be depicted in one of two ways—one in which the forces exerted on an object are represented as arrows pointing outward from a dot, and the other in which the forces are specifically drawn at the point on the object at which each force is exerted.

Unit Essential Questions

- At the macroscopic level, why forces can be categorized as either long-range (action-at-a-distance) forces or contact forces?
- What causes a gravitational field?
- What does the internal structure of a system determine?

Knowledge and Skills
Students will know…
Systems
- The student can create representations and models of natural or man-made phenomena and systems in the domain.
- The student can connect phenomena and models across spatial and temporal scales.

The Gravitational Field
- The student can apply mathematical routines to quantities that describe natural phenomena.
- The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

Contact Forces
- The student can justify claims with evidence.
- The student can construct explanations of phenomena based on evidence produced through scientific practices**.**

Newton's First Law
- The student can design a plan for collecting data to answer a particular scientific question. A3.

Newton's Third Law and Free-Body Diagrams
- The student can create representations and models of natural or man-made phenomena and systems in the domain.
- The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
- The student can justify claims with evidence.

- The student can construct explanations of phenomena based on evidence produced through scientific practices.
- The student can make claims and predictions about natural phenomena based on scientific theories and models.
- The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

Newton's Second Law

- The student can create representations and models of natural or man-made phenomena and systems in the domain.
- The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
- The student can re-express key elements of natural phenomena across multiple representations in the domain.
- The student can apply mathematical routines to quantities that describe natural phenomena.
- The student can design a plan for collecting data to answer a particular scientific question.
- The student can analyze data to identify patterns or relationships.
- The student can make claims and predictions about natural phenomena based on scientific theories and models.
- The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

Applications of Newton's Second Law

- The student can describe representations and models of natural or man-made phenomena and systems in the domain.
- The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
- The student can apply mathematical routines to quantities that describe natural phenomena.
- The student can estimate quantities that describe natural phenomena.
- 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.
- Express the motion of an object using narrative, mathematical, and graphical representations.
- Design an experimental investigation of the motion of an object.
- 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.

Performance Expectations:

Students will be able to…

- describe representations and models of natural or man-made phenomena and systems in the domain.
- use representations and models to analyze situations or solve problems qualitatively and quantitatively.
- apply mathematical routines to quantities that describe natural phenomena.
- estimate quantities that describe natural phenomena.
- evaluate the evidence provided by data sets in relation to a particular scientific question.
- make claims and predictions about natural phenomena based on scientific theories and models.
- 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.
- re-express a free-body diagram into a mathematical representation, and solve the mathematical representation for the acceleration of the object.

- **c**reate and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively.
- use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively
- evaluate, using given data, whether all the forces on a system or all the parts of a system have been identified.
- 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.
- 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.

EVIDENCE OF LEARNING

Assessment

What evidence will be collected and deemed acceptable to show that students truly "understand"?

- Teacher observations
- Lab Reports
- **End of Unit Assessment**
    - Students will use representations and models to analyze situations or solve problems qualitatively and quantitatively.
    - Students will evaluate evidence provided by data sets in relation to a particular scientific question.

Learning Activities

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

1. Changing Representations: Have students consider an accelerating two-object system from everyday life (e.g., person pushes a shopping cart, car pulls a trailer). Have them draw the forces on one object, then on the other, and then the external forces acting on the two-object system.
2. Desktop Experiment Task: Have students measure the coefficient of static friction of their shoe on a wood plank or metal track. Level 1: Use a spring scale. Level 2: Use a pulley, a spring, a toy bucket, and an electronic balance. Level 3: Use a protractor.
3. Desktop Experiment Task: Give students a yo-yo, a low mass, low friction pulley, 50 paper clips, and a scale. Have them find the acceleration of the falling, unrolling yo-yo and then determine the mass of the paper clips to attach to the free end of the string so that the paper clips stay at rest even as the yo-yo falls and the string passes over the pulley.
4. Working Backward: Student A writes a Newton's second law equation either with symbols or plugged-in numbers including units. Student B must then describe a situation that the equation applies to, including the object's velocity direction and how velocity is changing, a diagram, and a free-body diagram.
5. Troubleshooting: Students take some force-related problem from the homework or textbook (one that requires setting up Newton's second law and maybe more). Students write out a detailed solution that has exactly one mistake in it (not a calculation error). Post everyone's problems/ solutions, and then ask students to identify everyone else's errors. The last student to have his or her error found wins.

RESOURCES

Teacher Resources:

- https://apcentral.collegeboard.org/courses/resources/ap-physics-1-and-2-inquiry-based-lab-investigations?course=ap-physics-2
- https://apcentral.collegeboard.org/pdf/physics-multiple-representations-knowledge-sf.pdf?course=ap-physics-1

- https://apcentral.collegeboard.org/courses/resources/physics-instruction-using-video-analysis-technology?course=ap-physics-1
- https://apcentral.collegeboard.org/series/teaching-strategies-limited-class-time?course=ap-physics-1

Equipment Needed:

- Laptop connection for power point presentations
- Overhead Projector as needed
- Laboratory equipment as specified for unit

RAHWAY PUBLIC SCHOOLS CURRICULUM

UNIT OVERVIEW

Content Area: AP Physics

Unit Title: Circular Motion and Gravitation

Target Course/Grade Level: 11 - 12 grades

Unit Summary: Students will continue to enhance their understanding of the physical world using models and representations to create a more complete and complex model of motion, particularly as it relates to gravitational mass and inertial mass. Again, translation and connections are essential—students must be able to use content and science practices from the previous two units and apply them in different ways. While it's essential that students are able to calculate numerical answers to questions, it is more important that they can combine mathematical representations to make new representations that more accurately describe natural phenomena. For example, students should be comfortable combining equations for uniform circular motion with gravitational equations to describe the circular path of a satellite circling a planet. It is also vital that students are given opportunities to think about and discuss the impact that changes or modifications have on physical scenarios. For example, students should be able to use mathematical and graphical representations to determine how doubling the distance of a satellite from a planet will change the period of orbit and then justify their answer with evidence and reasoning. Specific preconceptions will be addressed in this unit, such as the idea of a centrifugal force.

Approximate Length of Unit: 6 weeks

LEARNING TARGETS

Learning Standards Addressed:
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 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]
3.C.2.2 Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [SP 7.2]
2.B.1.1 Apply F υρ = mg υρ 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 $g = G m/r^2$ 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 between the net force and the vector sum of the individual forces. [SP 4.2, 5.1]
3.B.1.3 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]
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]
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 express the results of the analysis using narrative, mathematical, and graphical representations. [SP 5.1]
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 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]
3.A.3.3 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]

Science Practices:

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems

- **SP 1.1** The student can create representations and models of natural or manmade phenomena and systems in the domain.
- **SP 1.2** The student can describe representations and models of natural or manmade phenomena and systems in the domain.
- **SP 1.3** The student can refine representations and models of natural or manmade phenomena and systems in the domain.
- **SP 1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
- **SP 1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain.

Science Practice 2: The student can use mathematics appropriately

- **SP 2.1** The student can justify the selection of a mathematical routine to solve problems.
- **SP 2.2** The student can apply mathematical routines to quantities that describe natural phenomena.
- **SP 2.3** The student can estimate numerically quantities that describe natural phenomena.

Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course

- **SP 3.1** The student can pose scientific questions.
- **SP 3.2** The student can refine scientific questions.
- **SP 3.3** The student can evaluate scientific questions.

Science Practice 4: The student can plan and implement data collection strategies in relation to a particular scientific question

- **SP 4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question.
- **SP 4.2** The student can design a plan for collecting data to answer a particular scientific question.
- **SP 4.3** The student can collect data to answer a particular scientific question.

• **SP 4.4** The student can evaluate sources of data to answer a particular scientific question.
Science Practice 5: The student can perform data analysis and evaluation of evidence
• **SP 5.1** The student can analyze data to identify patterns or relationships.
• **SP 5.2** The student can refine observations and measurements based on data analysis.
• **SP 5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question.
Science Practice 6: The student can work with scientific explanations and theories
• **SP 6.1** The student can justify claims with evidence.
• **SP 6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.
• **SP 6.3 T**he student can articulate the reasons that scientific explanations and theories are refined or replaced.
• **SP 6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models.
• **SP 6.5** The student can evaluate alternative scientific explanations**.**
Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains
• **SP 7.1** The student can connect phenomena and models across spatial and temporal scales.
• **SP 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.

NJ SLS Companion Standards: Reading and Writing Standards for History, Social Studies, Science, and Technical Subjects:

- **RST.9-10.1.** Accurately cite strong and thorough evidence from the text to support analysis of science and technical texts, attending to precise details for explanations or descriptions.
- **RST.9-10.2**. Determine the central ideas, themes, or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- **RST.9-10.3**. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.
- **RST.9-10.7.** Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.
- **WHST.9-10.1.** Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant sufficient textual and non-textual evidence.
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- **CRP9.** Model integrity, ethical leadership and effective management.
- **CRP11.** Use technology to enhance productivity.
- **CRP12.** Work productively in teams while using cultural global competence.

Unit Understandings
Students will understand that…

- 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.
- Certain types of forces are considered fundamental.

- At the macroscopic level, forces can be categorized as either long-range (action-ata-distance) forces or contact forces.
- A gravitational field is caused by an object with mass.
- Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
- The acceleration of the center of mass of a system is related to the net force exerted on the system.
- All forces share certain common characteristics when considered by observers in inertial reference frames.

Unit Essential Questions

- How can you describe the path of a satellite circulating around a planet?
- How do changes in the scenario affect the overall physical scenario?
- How can gravitational forces be calculated?
- How do you measure gravitational mass and inertial mass?

Knowledge and Skills
Students will know…

- A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.
  - a. Vector fields are represented by field vectors indicating direction and magnitude.
  - b. When more than one source object with mass or electric charge is present, the field value can be determined by vector addition.
  - c. Conversely, a known vector field can be used to make inferences about the number, relative size, and locations of sources.
- Gravitational forces are exerted at all scales and dominate at the largest distances and mass scales.
- Certain types of forces are considered fundamental.
- At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.
- Gravitational force describes the interaction of one object with mass with another object with mass. a. The gravitational force is always attractive. b. The magnitude of force between two spherically symmetric objects of mass m1 and m2 is G m m1 2 r 2 , where r is the center-to-center distance between the objects. c. In a narrow range of heights above Earth's surface, the local gravitational field, g, is approximately constant.
- A gravitational field is caused by an object with mass.
- A gravitational field υ g ρ 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 Earth, this gravitational force is called weight.
  - b. The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force.
  - c. If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in Newtons/kilogram) at that location.
- Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.

- Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
- 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.
    - c. The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity with time, and the center of mass velocity is equal to the rate of change of position of the center of mass with time.
    - d. The variables x, v, and a all refer to the center-of-mass quantities
- If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.
- 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 were extracted from its environment and the interactions with the environment were 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.
    - d. Free-body or force diagrams may be depicted in one of two ways—one in which the forces exerted on an object are represented as arrows pointing outward from a dot, and the other in which the forces are specifically drawn at the point on the object at which each force is exerted.
- An observer in a reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.
    - a. Displacement, velocity, and acceleration are all vector quantities.
    - b. Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values.
    - c. A choice of reference frame determines the direction and the magnitude of each of these quantities.
    - d. There are three fundamental interactions or forces in nature: the gravitational force, the electroweak force, and the strong force. The fundamental forces determine both the structure of objects and the motion of objects.
    - e. In inertial reference frames, forces are detected by their influence on the motion (specifically the velocity) of an object. So force, like velocity, is a vector quantity. A force vector has magnitude and direction. When multiple forces are exerted on an object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. The acceleration of the object is proportional to the net force.
    - f. The kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included.
    - g. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration.
    - h. This also includes situations where there is both a radial and tangential acceleration for an object moving in a circular path. For uniform circular motion of radius r, v is proportional to omega, ω (for

a given r), and proportional to r (for a given omega, ω). Given a radius r and a period of rotation T, students derive and apply $v = (2\pi r)/T$.

- 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.
- Forces are described by vectors.
    - a. Forces are detected by their influence on the motion of an object.
    - b. Forces have magnitude and direction
- 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.
- 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 Earth's surface, all objects fall (in a vacuum) with the same acceleration, regardless of their inertial mass.

Performance Expectations:

Students will be able to…

- Articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored.
- Use Newton's law of gravitation to calculate the gravitational force that two objects exert on each other and use that force in contexts other than orbital motion.
- 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).
- Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces.
- Apply F υρ = mg υρ 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.
- Apply $g = G m/r^2$ 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.
- 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.
- Design a plan for collecting data to measure gravitational mass and to measure inertial mass and to distinguish between the two experiments.
- Evaluate, using given data, whether all the forces on a system or whether all the parts of a system have been identified.

EVIDENCE OF LEARNING

Assessment

What evidence will be collected and deemed acceptable to show that students truly "understand"?

- Teacher observations

- Lab Reports
- **End of Unit Assessment**
  - Students will use Newton's law of gravitation to calculate the gravitational force that two objects exert on each other.
  - Students will use data to evaluate whether all the forces on a system have been identified.

Learning Activities

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

1. Desktop Experiment: Task Have students use the "My Solar System" PhET applet to create circular orbits of varying radii around the central star and record radius, period, and planet mass for various trials. Next, have them calculate the speed using $v = 2\pi r/T$ and force using $F = mv2/r$. Using the data, students show that gravitational force is directly proportional to mass and inversely proportional to radius.
2. Construct an Argument: Ask students to consider two identical objects moving in circles (or parts of circles) of different radii. Ask them to think of a situation where the object with the smaller radius has a greater net force and another situation where the object with the larger radius has a greater net force.
3. Changing Representations: Describe something a driver could be doing in a car (e.g., "turning the steering wheel to the right while pressing the brake"). Have students walk out the motion while holding out one arm representing the velocity vector and the other arm representing the acceleration vector.
4. Create a Plan: Find a data table on stopping distance. Have students determine the coefficient of static friction of the car's tires from this data and then create a new table of different car speeds and minimum turning radii to not skid.
5. Predict and Explain: Attach a pendulum of known weight (say, 2 N) to a force sensor and cause the bob to swing in a 180-degree arc. Ask students, "At the bottom, the bob is neither speeding up nor slowing down, so what force is registered at the bottom?" Expect students to (incorrectly) answer, "2 N."

RESOURCES

Teacher Resources:

- https://apcentral.collegeboard.org/courses/resources/ap-physics-1-and-2-inquiry-based-lab-investigations?course=ap-physics-2
- https://apcentral.collegeboard.org/pdf/physics-multiple-representations-knowledge-sf.pdf?course=ap-physics-1

Equipment Needed:

- Laptop connection for power point presentations
- Overhead Projector as needed
- Laboratory equipment as specified for unit

RAHWAY PUBLIC SCHOOLS CURRICULUM

UNIT OVERVIEW

Content Area: AP Physics

Unit Title: Energy

Target Course/Grade Level: 11-12 grades

Unit Summary: Students will be introduced to the idea of conservation as a foundational model of physics, along with the concept of work as the agent of change for energy. As in earlier units, students will once again utilize both familiar and new models and representations to analyze physical situations, now with force or energy as major components. Students will be encouraged to call upon their knowledge of Units 1–4 to determine the most appropriate technique and will be challenged to understand the limiting factors of each. Describing, creating, and using these representations will also help students grapple with common misconceptions that they may have about energy, such as whether or not a single object can "have" potential energy. A thorough understanding of these energy models will support students' ability to make predications—and ultimately justify claims with evidence—about physical situations. This is crucial, as the mathematical models and representations used in Unit 4 will mature throughout the course and appear in subsequent units.

Approximate Length of Unit: 6 weeks

LEARNING TARGETS

Learning Standards Addressed:

- **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 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 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]**

Science Practices:

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems

• **SP 1.1** The student can create representations and models of natural or manmade phenomena and systems in the domain**.**

• **SP 1.2** The student can describe representations and models of natural or manmade phenomena and systems in the domain.

• **SP 1.3** The student can refine representations and models of natural or manmade phenomena and systems in the domain.

• **SP 1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

• **SP 1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain.

Science Practice 2: The student can use mathematics appropriately

• **SP 2.1** The student can justify the selection of a mathematical routine to solve problems.

• **SP 2.2** The student can apply mathematical routines to quantities that describe natural phenomena.

• **SP 2.3** The student can estimate numerically quantities that describe natural phenomena.

Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course

• **SP 3.1** The student can pose scientific questions.

• **SP 3.2** The student can refine scientific questions.

• **SP 3.3** The student can evaluate scientific questions.

Science Practice 4: The student can plan and implement data collection strategies in relation to a particular scientific question

• **SP 4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question.

• **SP 4.2** The student can design a plan for collecting data to answer a particular scientific question.

• **SP 4.3** The student can collect data to answer a particular scientific question.

• **SP 4.4** The student can evaluate sources of data to answer a particular scientific question.

Science Practice 5: The student can perform data analysis and evaluation of evidence

• **SP 5.1** The student can analyze data to identify patterns or relationships.

• **SP 5.2** The student can refine observations and measurements based on data analysis.

• **SP 5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

Science Practice 6: The student can work with scientific explanations and theories

• **SP 6.1** The student can justify claims with evidence.

• **SP 6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.

• **SP 6.3 T**he student can articulate the reasons that scientific explanations and theories are refined or replaced.

• **SP 6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models.

• **SP 6.5** The student can evaluate alternative scientific explanations**.**

Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains

• **SP 7.1** The student can connect phenomena and models across spatial and temporal scales.

• **SP 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.

NJ SLS Companion Standards: Reading and Writing Standards for History, Social Studies, Science, and Technical Subjects:

- **RST.9-10.1.** Accurately cite strong and thorough evidence from the text to support analysis of science and technical texts, attending to precise details for explanations or descriptions.
- **RST.9-10.2**. Determine the central ideas, themes, or conclusions of a text; trace the text’s explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- **RST.9-10.3**. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.
- **RST.9-10.7.** Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.
- **WHST.9-10.1.** Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant sufficient textual and non-textual evidence.
    - A. Introduce precise claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that establishes clear relationships among the claim(s), counterclaims, reasons, and evidence.
- **WHST.9-10.4.** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
- **WHST.9-10.5.** Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
- **WHST.9-10.6.** Use technology, including the Internet, to produce, share, and update writing products, taking advantage of technology’s capacity to link to other information and to display information flexibly and dynamically.

Interdisciplinary Connections and Standards:
Mathematics:

- **MP.2** Reason abstractly and quantitatively.
- **MP.4** Model with mathematics.
- **HSN-Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- **HSN-Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
- **HSN-Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- **HSA-SSE.A.1** Interpret expressions that represent a quantity in terms of its context.
- **HSA-SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- **HSA-CED.A.1** Create equations and inequalities in one variable and use them to solve problems.
- **HSA-CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- **HSA-CED.A.4** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- **HSF-IF.C.7** Graph functions expressed symbolically and show key features of the graph, by in hand in simple cases and using technology for more complicated cases.
- **HSS-ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots

Technology:

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.

- **Strand A. Technology Operations and Concepts:** Students demonstrate a sound understanding of technology concepts, systems and operations.
- **Strand B. Creativity and Innovation**: Students demonstrate creative thinking, construct knowledge and develop innovative products and process using technology.
- **Strand C**. **Communication and Collaboration:** Students use digital media and environments to communicate and work collaboratively, including at a distance, to support individual learning and contribute to the learning of others
- **Strand D**. **Digital Citizenship:** Students understand human, cultural, and societal issues related to technology and practice legal and ethical behavior
- **Strand E**: **Research and Information Fluency**: Students apply digital tools to gather, evaluate, and use information.
- **Strand F: Critical thinking, problem solving, and decision making:** Students use critical thinking skills to plan and conduct research, manage projects, solve problems, and make informed decisions using appropriate digital tools and resources.

21st Century Learning Standards:
Career Ready Practices:

- **CRP1.** Act as a responsible and contributing citizen and employee.
- **CRP2.** Apply appropriate academic and technical skills.
- **CRP4.** Communicate clearly and effectively and with reason.
- **CRP5.** Consider the environmental, social and economic impacts of decisions.
- **CRP6.** Demonstrate creativity and innovation.
- **CRP7.** Employ valid and reliable research strategies.
- **CRP8.** Utilize critical thinking to make sense of problems and persevere in solving them.
- **CRP9.** Model integrity, ethical leadership and effective management.
- **CRP11.** Use technology to enhance productivity.
- **CRP12.** Work productively in teams while using cultural global competence.

Unit Understandings
Students will understand that…

- 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.
- A force exerted on an object can change the kinetic energy of the object.
- Interactions with other objects or systems can change the total energy of a system.
- The energy of a system is conserved.

Unit Essential Questions

- What is a system?
- What types of systems are there and how does the type of system affect energy, charge, linear, and angular momentum?
- What are the different ways in which energy is conserved?

Knowledge and Skills:
Students will know…

- A system is an object or a collection of objects. The objects are treated as having no internal structure.
- For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.
- An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system.
- The placement of a boundary between a system and its environment is a decision made by the person considering the situation in order to simplify or otherwise assist in analysis.
- The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples include gravitational potential energy, elastic potential energy, and kinetic energy.
    - a. A rotating, rigid body may be considered to be a system and may have both translational and rotational kinetic energy.
    - b. Although thermodynamics is not part of Physics 1, included is the idea that, during an inelastic collision, some of the mechanical energy dissipates as (converts to) thermal energy.
- The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the interval that the force is exerted.
  a. Only the component of the net force exerted on an object parallel or antiparallel to the displacement of the object will increase (parallel) or decrease (antiparallel) the kinetic energy of the object.
  b. The magnitude of the change in the kinetic energy is the product of the magnitude of the displacement and of the magnitude of the component of force parallel or antiparallel to the displacement.
  c. The component of the net force exerted on an object perpendicular to the direction of the displacement of the object can change the direction of the motion of the object without changing the kinetic energy of the object. This should include uniform circular motion and projectile motion.
  d. The kinetic energy of a rigid system may be translational, rotational, or a combination of both. The change in the rotational kinetic energy of a rigid system is the product of the angular displacement and the net torque.
- Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the forces is parallel to its displacement. The process through which the energy is transferred is called work.
  a. If the force is constant during a given displacement, then the work done is the product of the displacement and the component of the force parallel or antiparallel to the displacement.
  b. Work (change in energy) can be found from the area under a graph of the magnitude of the force component parallel to the displacement versus displacement.

- Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects.
- A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy.
- A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces.
  a. The work done by a conservative force is independent of the path taken. The work description is used for forces external to the system. Potential energy is used when the forces are internal interactions between parts of the system.
  b. Changes in the internal structure can result in changes in potential energy. Examples include mass-spring oscillators and objects falling in a gravitational field.
  c. The change in electric potential in a circuit is the change in potential energy per unit charge.
  - The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system.
    a. Since energy is constant in a closed system, changes in a system's potential energy can result in changes to the system's kinetic energy.
    b. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system.
  - Energy can be transferred by an external force exerted on an object or a system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system.

Performance Expectations:

Students will be able to…

- Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.]
- 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.
- Use net force and velocity vectors to determine qualitatively whether the kinetic energy of an object would increase, decrease, or remain unchanged.
- 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
- Apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of the object.
- 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
- Predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system.
- 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.
- 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
- 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.
- Translate between a representation of a single object, which can only have kinetic energy, and a system that includes the object, which may have both kinetic and potential energies
- 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.

- Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy.
- Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system**.**
- 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
- Describe and make predictions about the internal energy of systems.
- Calculate changes in kinetic energy and potential energy of a system using information from representations of that system.
- 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
- 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.
- 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
- 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).
- 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.

EVIDENCE OF LEARNING

Assessment

What evidence will be collected and deemed acceptable to show that students truly "understand"?

- Teacher observations
- Lab Reports
- **End of Unit Assessment**
    - Students will calculate changes in energy
    - Students will predict and calculate energy transfer
    - Students will use models to predict energy changes

Learning Activities

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

1. Concept-Oriented Demonstration: Release a low-friction cart (mass m) from the top of a ramp, have students time (t) how long it takes to reach the bottom, and measure the release height h and track length L. Have students calculate velocity using v = L/t, and then calculate mgh and ½mv2. The two energies are different; explain what incorrect assumptions lead to the difference in energies.
2. Desktop Experiment Task: Give each group a spring-loaded ball launcher, scale, and meterstick. Ask them to determine the spring constant of the spring in the launcher.
3. Four-Square Problem Solving: First square: Describe an everyday situation (e.g., "a car goes downhill, speeding up even as the brakes are pressed") along with a diagram. Second square: Free-body diagram with an arrow off to the side representing the object's displacement. Third square: Energy bar charts (initial and

final). Fourth square: For each force on the free-body diagram, state whether that force performs positive or negative work and what energy transformation that force is responsible for.

4. Construct an Argument: Ask students to consider a cart that rolls from rest down a ramp and then around a vertical loop. For the cart to complete the loop without falling out, the cart must be released at a height higher than the top of the loop. Have students explain why this is the case using energy and circular motion principles.
5. Working Backward: Student A writes a conservation of energy equation (either symbolically or with numbers and units plugged in). Student B then describes a situation that the equation could apply to, draws a diagram, and draws energy bar charts.

RESOURCES

Teacher Resources:

- https://apcentral.collegeboard.org/courses/resources/ap-physics-1-and-2-inquiry-based-lab-investigations?course=ap-physics-2
- https://apcentral.collegeboard.org/pdf/physics-conservation-concepts.pdf?course=ap-physics-1
- https://apcentral.collegeboard.org/pdf/physics-multiple-representations-knowledge-sf.pdf?course=ap-physics-1

Equipment Needed:

- Laptop connection for power point presentations
- Overhead Projector as needed
- Laboratory equipment as specified for unit

RAHWAY PUBLIC SCHOOLS CURRICULUM

UNIT OVERVIEW

Content Area: AP Physics

Unit Title: Momentum

Target Course/Grade Level: 11-12 grades

Unit Summary: This unit introduces students to the relationship between force, time, and momentum via calculations, data analysis, designing experiments, and making predictions. Students will learn how to use new models and representations to illustrate the law of the conservation of momentum of objects and systems while simultaneously building on their knowledge of previously studied representations. Using the law of the conservation of momentum to analyze physical situations gives students a more complete picture of forces and leads them to revisit their misconceptions surrounding Newton's third law. Students will also have the opportunity to make connections between the conserved quantities of momentum and energy to determine under what conditions each quantity is conserved. It's essential that students are not only comfortable solving numerical equations (such as the speed of a system after an inelastic collision) but also confident in their ability to discuss when momentum is conserved and how the type of collision affects the outcome.

Approximate Length of Unit: 5 weeks

LEARNING TARGETS

Learning Standards Addressed:

- **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 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 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]**

Science Practices:

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems

• **SP 1.1** The student can create representations and models of natural or manmade phenomena and systems in the domain**.**

• **SP 1.2** The student can describe representations and models of natural or manmade phenomena and systems in the domain.

• **SP 1.3** The student can refine representations and models of natural or manmade phenomena and systems in the domain.

• **SP 1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

• **SP 1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain.

Science Practice 2: The student can use mathematics appropriately

• **SP 2.1** The student can justify the selection of a mathematical routine to solve problems.

• **SP 2.2** The student can apply mathematical routines to quantities that describe natural phenomena.

• **SP 2.3** The student can estimate numerically quantities that describe natural phenomena.
Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course
• **SP 3.1** The student can pose scientific questions.
• **SP 3.2** The student can refine scientific questions.
• **SP 3.3** The student can evaluate scientific questions.
Science Practice 4: The student can plan and implement data collection strategies in relation to a particular scientific question
• **SP 4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question.
• **SP 4.2** The student can design a plan for collecting data to answer a particular scientific question.
• **SP 4.3** The student can collect data to answer a particular scientific question.
• **SP 4.4** The student can evaluate sources of data to answer a particular scientific question.
Science Practice 5: The student can perform data analysis and evaluation of evidence
• **SP 5.1** The student can analyze data to identify patterns or relationships.
• **SP 5.2** The student can refine observations and measurements based on data analysis.
• **SP 5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question.
Science Practice 6: The student can work with scientific explanations and theories
• **SP 6.1** The student can justify claims with evidence.
• **SP 6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.
• **SP 6.3 T**he student can articulate the reasons that scientific explanations and theories are refined or replaced.
• **SP 6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models.
• **SP 6.5** The student can evaluate alternative scientific explanations**.**
Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains
• **SP 7.1** The student can connect phenomena and models across spatial and temporal scales.
• **SP 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.

NJ SLS Companion Standards: Reading and Writing Standards for History, Social Studies, Science, and Technical Subjects:

- **RST.9-10.1.** Accurately cite strong and thorough evidence from the text to support analysis of science and technical texts, attending to precise details for explanations or descriptions.
- **RST.9-10.2**. Determine the central ideas, themes, or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- **RST.9-10.3**. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.
- **RST.9-10.7.** Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.
- **WHST.9-10.1.** Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant sufficient textual and non-textual evidence.
    - A. Introduce precise claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that establishes clear relationships among the claim(s), counterclaims, reasons, and evidence.
- **WHST.9-10.4.** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

- **WHST.9-10.5.** Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
- **WHST.9-10.6.** Use technology, including the Internet, to produce, share, and update writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.

Interdisciplinary Connections and Standards:
Mathematics:

- **MP.2** Reason abstractly and quantitatively.
- **MP.4** Model with mathematics.
- **HSN-Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- **HSN-Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
- **HSN-Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- **HSA-SSE.A.1** Interpret expressions that represent a quantity in terms of its context.
- **HSA-SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- **HSA-CED.A.1** Create equations and inequalities in one variable and use them to solve problems.
- **HSA-CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- **HSA-CED.A.4** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- **HSF-IF.C.7** Graph functions expressed symbolically and show key features of the graph, by in hand in simple cases and using technology for more complicated cases.
- **HSS-ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots

Technology:

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.

- **Strand A. Technology Operations and Concepts:** Students demonstrate a sound understanding of technology concepts, systems and operations.
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- **Strand D**. **Digital Citizenship:** Students understand human, cultural, and societal issues related to technology and practice legal and ethical behavior
- **Strand E**: **Research and Information Fluency**: Students apply digital tools to gather, evaluate, and use information.
- **Strand F: Critical thinking, problem solving, and decision making:** Students use critical thinking skills to plan and conduct research, manage projects, solve problems, and make informed decisions using appropriate digital tools and resources.

21st Century Learning Standards:
Career Ready Practices:

- **CRP1.** Act as a responsible and contributing citizen and employee.
- **CRP2.** Apply appropriate academic and technical skills.
- **CRP4.** Communicate clearly and effectively and with reason.
- **CRP5.** Consider the environmental, social and economic impacts of decisions.
- **CRP6.** Demonstrate creativity and innovation.

- **CRP7.** Employ valid and reliable research strategies.
- **CRP8.** Utilize critical thinking to make sense of problems and persevere in solving them.
- **CRP9.** Model integrity, ethical leadership and effective management.
- **CRP11.** Use technology to enhance productivity.
- **CRP12.** Work productively in teams while using cultural global competence.

Unit Understandings

Students will understand that…

- A force exerted on an object can change the momentum of the object.
- The change in momentum of an object is a vector in the direction of the net force exerted on the object.
- The change in momentum of an object occurs over a time interval.
  a. The force that one object exerts on a second object changes the momentum of the second object (in the absence of other forces on the second object).
  b. The change in momentum of that object depends on the impulse, which is the product of the average force and the time interval during which the interaction occurred.
- Interactions with other objects or systems can change the total linear momentum of a system.
- 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.
- The linear momentum of a system is conserved.

Unit Essential Questions

- How can a force change the momentum of an object?
- How can interactions with other objects or systems change the total linear momentum of a system?

Knowledge and Skills

Students will know…

- The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass.
- For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.
- In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.
  - In a closed system, the linear momentum is constant throughout the collision.
  - In a closed system, the kinetic energy after an elastic collision is the same
- In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.
  - a. In a closed system, the linear momentum is constant throughout the collision.
  -
  - b. In a closed system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision.
- 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.
- Apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy.
- Analyze data that verify conservation of momentum in collisions with and without an external frictional force.

- 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.
- The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1 includes no calculations of centers 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.]
    a. The center of mass of a system depends on the masses and positions of the objects in the system. In an isolated system (a system with no external forces), the velocity of the center of mass does not change.
    b. When objects in a system collide, the velocity of the center of mass of the system will not change unless an external force is exerted on the system.
    c. Included in Physics 1 is the idea that, where there is both a heavier and lighter mass, the center of mass is closer to the heavier mass. Only a qualitative understanding of this concept is required.
- The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted.
  a. The units for momentum are the same as the units of the area under the curve of a force versus time graph.
  b. The change in linear momentum and force are both vectors in the same direction.

Performance Expectations:

Students will be able to…

- Analyze data to characterize the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted.
- Design a plan for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time.
- 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.).
- 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.
- 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.
- Perform an analysis on data presented as a force-time graph and predict the change in momentum of a system.
- Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.
- Make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions.
- 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.
- 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.
- 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

- 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.
- 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.
- 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).

EVIDENCE OF LEARNING

Assessment

What evidence will be collected and deemed acceptable to show that students truly "understand"?

- Lab reports
- Teacher observations
- **End of Unit Assessment**
  - Students will 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.
  - Students will 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.).
  - Students will 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.

Learning Activities

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

1. Conflicting Contentions: Ask students to imagine a pitcher throwing a baseball and a catcher catching it. Students will debate who exerted more force on the ball (no way to know), who applied greater impulse (same for both), and who did a greater magnitude of net work on the ball (same). Repeat for a pitcher throwing the baseball and a batter hitting it back at the same speed.
2. Desktop Experiment Task: Connect a spring-loaded lanyard between a cart and force sensor, with a motion sensor on the other side of the cart. Have students take force and motion versus time data as the lanyard contracts and pulls, accelerating the cart. Show that impulse applied to the cart equals the cart's change in momentum.
3. Bar Chart/Construct an Argument: Have students use momentum bar charts to explain why a dart bouncing off a cart makes the cart move faster than if the dart sticks to the cart, passes through the cart, or stops and drops after colliding with the cart.
4. Predict and Explain/Concept-Oriented Demonstration: Have a cart crash into a force sensor set to its highest setting in three different ways: cart sticks to sensor, cart bounces off the sensor on its hard side, and cart bounces off the sensor with its spring side. Have students predict in which case more force is registered, and explain why after each experiment is done.
5. Desktop Experiment Task: Have two carts with different masses collide in a non-stick collision. Film the carts with a phone camera from above, with a meter stick next to the track. Have students use a frame-by-frame review app to determine the cart's initial/final speeds, whether momentum was conserved, and whether the collision was elastic.

RESOURCES

Teacher Resources:

- https://apcentral.collegeboard.org/courses/resources/ap-physics-1-and-2-inquiry-based-lab-investigations?course=ap-physics-2
- https://apcentral.collegeboard.org/pdf/physics-conservation-concepts.pdf?course=ap-physics-1

Equipment Needed:

- Laptop connection for power point presentations
- Overhead Projector as needed
- Laboratory equipment as specified for unit

RAHWAY PUBLIC SCHOOLS CURRICULUM

UNIT OVERVIEW

Content Area: AP Physics

Unit Title: Simple Harmonic Motion

Target Course/Grade Level: 11 - 12 grades

Unit Summary: Students will continue to use the same tools, techniques, and models that they have been using throughout this course. However, they will now use them to analyze a new type of motion: simple harmonic motion. Although simple harmonic motion is unique, students will learn that even in new situations, the fundamental laws of physics remain the same. Energy bar charts, as well as free-body diagrams, become increasingly important as students work toward determining which model is most appropriate for a given physical situation. Preconceptions—such as the relationship between the amplitude and period of oscillation—will also be addressed to provide students with a more nuanced awareness of simple harmonic motion.
Students are expected to use the content knowledge they gained in the first five units to make and defend claims while also making connections in and across the content topics and big ideas. Throughout this unit, students will be asked to create force, energy, momentum, and position versus time graphs for a single scenario and to make predictions based on their representations.

Approximate Length of Unit: 5 weeks

LEARNING TARGETS

Learning Standards Addressed:

- **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 a force. **[SP 2.2, 6.2]**
- **5B.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]**

Science Practices:

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems

• **SP 1.1** The student can create representations and models of natural or manmade phenomena and systems in the domain**.**

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- **CRP6.** Demonstrate creativity and innovation.
- **CRP7.** Employ valid and reliable research strategies.
- **CRP8.** Utilize critical thinking to make sense of problems and persevere in solving them.
- **CRP9.** Model integrity, ethical leadership and effective management.
- **CRP11.** Use technology to enhance productivity.
- **CRP12.** Work productively in teams while using cultural global competence.

Unit Understandings
Students will understand that…

- Classically, the acceleration of an object interacting with other objects can be predicted
- The energy of a system is conserved.

Unit Essential Questions

- Why is energy conserved?
- How is energy conserved?

Knowledge and Skills
Students will know…

- A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy.
- The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system.
    a. Since energy is constant in a closed system, changes in a system's potential energy can result in changes to the system's kinetic energy.

  b. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system.
- A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces.

a. The work done by a conservative force is independent of the path taken. The work description is used for forces external to the system. Potential energy is used when the forces are internal interactions between parts of the system.
b. Changes in the internal structure can result in changes in potential energy. Examples include mass-spring oscillators and objects falling in a gravitational field.
c. The change in electric potential in a circuit is the change in potential energy per unit charge.

- Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples include gravitational force exerted by Earth on a simple pendulum and mass-spring oscillator.
    a. For a spring that exerts a linear restoring force, the period of a mass-spring oscillator increases with mass and decreases with spring stiffness.
    b. For a simple pendulum, the period increases with the length of the pendulum and decreases with the magnitude of the gravitational field.
    c. Minima, maxima, and zeros of position, velocity, and acceleration are features of harmonic motion. Students should be able to calculate force and acceleration for any given displacement for an object oscillating on a spring.

Performance Expectations:

Students will be able to…

- Predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties
- 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
- 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
- Construct a qualitative and/ or quantitative explanation of oscillatory behavior given evidence of a restoring a force.
- 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.
- Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy
- Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system
- 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

EVIDENCE OF LEARNING

Assessment

What evidence will be collected and deemed acceptable to show that students truly "understand"?

- Lab reports
- Teacher observations
- **Unit Assessment**
    - Students will 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
- Students will construct a qualitative and/ or quantitative explanation of oscillatory behavior given evidence of a restoring a force.

Learning Activities

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

1. Desktop Experiment Task: Have students determine the spring constant of a spring using (1) known masses and meter stick only and then (2) known masses and stopwatch only.
2. Desktop Experiment Task: Have students use a pendulum to measure the acceleration of gravity. Ask them to refine the experiment from single-trial calculation, to taking an average, to making a graph of linearized data.
3. Predict and Explain: Make a pendulum bob oscillate with the other end of the string "clamped" between your fingers. While the bob oscillates, pull the string through your fingers so that the string length is shortened. Before doing this, ask students what will happen to the period of the oscillation and the amplitude (measured in degrees), and then explain why the period decreases and the amplitude angle increases.
4. Construct an Argument: A cart wiggles on a horizontal spring. A blob of clay is dropped on the cart and sticks (could be when the cart is at the center or at one end). Ask students to explain what happened to the period, total energy, amplitude of motion, and maximum speed?
5. Create a Plan: Students choose a song and find its tempo (beats per minute). Students then must build a pendulum so that it swings back and forth on each beat. Students are then given a spring. They must find the spring's constant and then find the amount of mass necessary to make the spring-mass oscillate on each beat.

RESOURCES

Teacher Resources:

- https://apcentral.collegeboard.org/courses/resources/ap-physics-1-and-2-inquiry-based-lab-investigations?course=ap-physics-2

Equipment Needed:

- Laptop connection for power point presentations
- Laboratory equipment as specified for unit

RAHWAY PUBLIC SCHOOLS CURRICULUM

UNIT OVERVIEW

Content Area: AP Physics

Unit Title: Torque and Rotational Motion

Target Course/Grade Level: 11-12 grades

Unit Summary: The study of mechanical physics by introducing students to torque and rotational motion. Although these topics present more complex scenarios, the tools of analysis remain the same:

During their study of torque and rotational motion, students will be confronted with different ways of thinking about and modeling forces. As in previous units, it's critical that students are given opportunities to create and use representations and models to make predictions and justify claims. It's equally important that students are comfortable deriving new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts.

Unit 7 also focuses on the mathematical practice of estimating quantities that can describe natural phenomena. For example, students need to be able to estimate the torque on an object caused by various forces in comparison to other situations.

Throughout this unit, students will have opportunities to compare and connect their understanding of linear and rotational motion, dynamics, energy, and momentum to

Approximate Length of Unit: 6 weeks

LEARNING TARGETS

Learning Standards Addressed:

- **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 1.4, 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]**

- **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 1.4, 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]**
- **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]**

Science Practices:

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems

• **SP 1.1** The student can create representations and models of natural or manmade phenomena and systems in the domain**.**
• **SP 1.2** The student can describe representations and models of natural or manmade phenomena and systems in the domain.
• **SP 1.3** The student can refine representations and models of natural or manmade phenomena and systems in the domain.
• **SP 1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
• **SP 1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain.

Science Practice 2: The student can use mathematics appropriately

• **SP 2.1** The student can justify the selection of a mathematical routine to solve problems.
• **SP 2.2** The student can apply mathematical routines to quantities that describe natural phenomena.
• **SP 2.3** The student can estimate numerically quantities that describe natural phenomena.

Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course

• **SP 3.1** The student can pose scientific questions.
• **SP 3.2** The student can refine scientific questions.
• **SP 3.3** The student can evaluate scientific questions.

Science Practice 4: The student can plan and implement data collection strategies in relation to a particular scientific question

• **SP 4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question.
• **SP 4.2** The student can design a plan for collecting data to answer a particular scientific question.
• **SP 4.3** The student can collect data to answer a particular scientific question.
• **SP 4.4** The student can evaluate sources of data to answer a particular scientific question.

Science Practice 5: The student can perform data analysis and evaluation of evidence

• **SP 5.1** The student can analyze data to identify patterns or relationships.
• **SP 5.2** The student can refine observations and measurements based on data analysis.
• **SP 5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

Science Practice 6: The student can work with scientific explanations and theories

• **SP 6.1** The student can justify claims with evidence.
• **SP 6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.
• **SP 6.3 T**he student can articulate the reasons that scientific explanations and theories are refined or replaced.
• **SP 6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models.
• **SP 6.5** The student can evaluate alternative scientific explanations**.**

Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains

• **SP 7.1** The student can connect phenomena and models across spatial and temporal scales.
• **SP 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.

NJ SLS Companion Standards: Reading and Writing Standards for History, Social Studies, Science, and Technical Subjects:

- **RST.9-10.1.** Accurately cite strong and thorough evidence from the text to support analysis of science and technical texts, attending to precise details for explanations or descriptions.

- **RST.9-10.2**. Determine the central ideas, themes, or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- **RST.9-10.3**. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.
- **RST.9-10.7.** Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.
- **WHST.9-10.1.** Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant sufficient textual and non-textual evidence.
    - A. Introduce precise claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that establishes clear relationships among the claim(s), counterclaims, reasons, and evidence.
- **WHST.9-10.4.** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
- **WHST.9-10.5.** Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
- **WHST.9-10.6.** Use technology, including the Internet, to produce, share, and update writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.

Interdisciplinary Connections and Standards:
Mathematics:

- **MP.2** Reason abstractly and quantitatively.
- **MP.4** Model with mathematics.
- **HSN-Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- **HSN-Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.
- **HSN-Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- **HSA-SSE.A.1** Interpret expressions that represent a quantity in terms of its context.
- **HSA-SSE.B.3** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- **HSA-CED.A.1** Create equations and inequalities in one variable and use them to solve problems.
- **HSA-CED.A.2** Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- **HSA-CED.A.4** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- **HSF-IF.C.7** Graph functions expressed symbolically and show key features of the graph, by in hand in simple cases and using technology for more complicated cases.
- **HSS-ID.A.1** Represent data with plots on the real number line (dot plots, histograms, and box plots

Technology:

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.

- **Strand A. Technology Operations and Concepts:** Students demonstrate a sound understanding of technology concepts, systems and operations.
- **Strand B. Creativity and Innovation**: Students demonstrate creative thinking, construct knowledge and develop innovative products and process using technology.
- **Strand C**. **Communication and Collaboration:** Students use digital media and environments to communicate and work collaboratively, including at a distance, to support individual learning and contribute to the learning of others
- **Strand D**. **Digital Citizenship:** Students understand human, cultural, and societal issues related to technology and practice legal and ethical behavior

- **Strand E**: **Research and Information Fluency**: Students apply digital tools to gather, evaluate, and use information.
- **Strand F: Critical thinking, problem solving, and decision making:** Students use critical thinking skills to plan and conduct research, manage projects, solve problems, and make informed decisions using appropriate digital tools and resources.

21st Century Learning Standards:
Career Ready Practices:

- **CRP1.** Act as a responsible and contributing citizen and employee.
- **CRP2.** Apply appropriate academic and technical skills.
- **CRP4.** Communicate clearly and effectively and with reason.
- **CRP5.** Consider the environmental, social and economic impacts of decisions.
- **CRP6.** Demonstrate creativity and innovation.
- **CRP7.** Employ valid and reliable research strategies.
- **CRP8.** Utilize critical thinking to make sense of problems and persevere in solving them.
- **CRP9.** Model integrity, ethical leadership and effective management.
- **CRP11.** Use technology to enhance productivity.
- **CRP12.** Work productively in teams while using cultural global competence.

Unit Understandings
Students will understand that…

- All forces share certain common characteristics when considered by observers in inertial reference frames.
- A force exerted on an object can cause a torque on that object.
- A net torque exerted on a system by other objects or systems will change the angular momentum of the system.
- The angular momentum of a system is conserved.

Unit Essential Questions

- How is the angular momentum of a system conserved?
- How can forces exerted on an object cause a torque on that object?
- What common characteristics do forces share?

Knowledge and Skills
Students will know…

- Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis.
  a. The lever arm is the perpendicular distance from the axis of rotation or revolution to the line of application of the force.
  b. The magnitude of the torque is the product of the magnitude of the lever arm and the magnitude of the force.
  c. The net torque on a balanced system is zero.
- The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis.
  a. Rotational motion can be described in terms of angular displacement, angular velocity, and angular acceleration about a fixed axis.
  b. Rotational motion of a point can be related to linear motion of the point using the distance of the point from the axis of rotation.
  c. The angular acceleration of an object or a rigid system can be calculated from the net torque and the rotational inertia of the object or rigid system.
- A torque exerted on an object can change the angular momentum of an object.

a. Angular momentum is a vector quantity, with its direction determined by a right-hand rule.
b. The magnitude of angular momentum of a point object about an axis can be calculated by multiplying the perpendicular distance from the axis of rotation to the line of motion by the magnitude of linear momentum.
c. The magnitude of angular momentum of an extended object can also be found by multiplying the rotational inertia by the angular velocity. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense of what factors affect rotational inertia—for example, why a hoop has more rotational inertia than a puck of the same mass and radius.
d. The change in angular momentum of an object is given by the product of the average torque and the time the torque is exerted.

- Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis.
  a. The lever arm is the perpendicular distance from the axis of rotation or revolution to the line of application of the force.
  b. The magnitude of the torque is the product of the magnitude of the lever arm and the magnitude of the force.
  c. The net torque on a balanced system is zero.
- The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis.
  a. Rotational motion can be described in terms of angular displacement, angular velocity, and angular acceleration about a fixed axis.
  b. Rotational motion of a point can be related to linear motion of the point using the distance of the point from the axis of rotation.
  c. The angular acceleration of an object or a rigid system can be calculated from the net torque and the rotational inertia of the object or rigid system
- A torque exerted on an object can change the angular momentum of an object.
  a. Angular momentum is a vector quantity, with its direction determined by a right-hand rule.
  b. The magnitude of angular momentum of a point object about an axis can be calculated by multiplying the perpendicular distance from the axis of rotation to the line of motion by the magnitude of linear momentum.
  c. The magnitude of angular momentum of an extended object can also be found by multiplying the rotational inertia by the angular velocity. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense of what factors affect rotational inertia—for example, why a hoop has more rotational inertia than a puck of the same mass and radius.
  d. The change in angular momentum of an object is given by the product of the average torque and the time the torque is exerted.
- Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending on whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis.
- The angular momentum of a system may change due to interactions with other objects or systems.
  a. The angular momentum of a system with respect to an axis of rotation is the sum of the angular momenta, with respect to that axis, of the objects that make up the system.
  b. The angular momentum of an object about a fixed axis can be found by multiplying the momentum of the particle by the perpendicular distance from the axis to the line of motion of the object.
  c. Alternatively, the angular momentum of a system can be found from the product of the system's rotational inertia and its angular velocity. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation.
- Alternatively, the angular momentum of a system can be found from the product of the system's rotational inertia and its angular velocity. Students do not need to know the equation for an object's

rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation.

- The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted.
- If the net external torque exerted on the system is zero, the angular momentum of the system does not change.
- The angular momentum of a system is determined by the locations and velocities of the objects that make up the system. The rotational inertia of an object or a system depends on the distribution of mass within the object or system. Changes in the radius of a system or in the distribution of mass within the system result in changes in the system's rotational inertia, and hence in its angular velocity and linear speed for a given angular momentum. Examples include elliptical orbits in an Earth-satellite system. Mathematical expressions for the moments of inertia will be provided where needed. Students will not be expected to know the parallel axis theorem. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation.
  Relevant Equation: $I = mr^2$
- An observer in a reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.
  a. Displacement, velocity, and acceleration are all vector quantities.
  b. Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values.
  c. A choice of reference frame determines the direction and the magnitude of each of these quantities.
  d. There are three fundamental interactions or forces in nature: the gravitational force, the electroweak force, and the strong force. The fundamental forces determine both the structure of objects and the motion of objects.
  e. In inertial reference frames, forces are detected by their influence on the motion (specifically the velocity) of an object. So force, like velocity, is a vector quantity. A force vector has magnitude and direction. When multiple forces are exerted on an object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. The acceleration of the object is proportional to the net force.
  f. The kinematic equations only apply to constant acceleration situations.
  g. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration.
  h. This also includes situations where there is both a radial and tangential acceleration for an object moving in a circular path.

Performance Expectations:

Students will be able to…

- Express the motion of an object using narrative, mathematical, and graphical representations.
- 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.]
- 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
- 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.
- 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.
- 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.

- Use representations of the relationship between force and torque.
- Compare the torques on an object caused by various forces.
- Estimate the torque on an object caused by various forces in comparison with other situations.
- Design an experiment and analyze data testing a question about torques in a balanced rigid system
- Calculate torques on a two-dimensional system in static equilibrium by examining a representation or model (such as a diagram or physical construction).
- 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**.**
- 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.
- 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.
- 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.
- 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.
- 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.
- 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
- 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.
- 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.
- 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.
- 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.
- Make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque
- Make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero.
- 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.

EVIDENCE OF LEARNING

Assessment

What evidence will be collected and deemed acceptable to show that students truly "understand"?

- Lab reports
- Teacher observations
- **End of Unit Assessment**

- Students will explain the angular momentum of a system and how it is conserved
- Students will explain how forces exerted on an object can cause a torque on that object.
- Students will explicate common characteristics of forces.

Learning Activities

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

1. Predict and Explain: Spin a bike wheel (preferably with the tire removed so that it will roll on its metal rims), and release it from rest on a floor or long table. Have students predict what will happen to the wheel's linear velocity (will increase) and its angular velocity (will decrease) as the wheel "peels out." Then explain why this happens using a force diagram.
2. Desktop Experiment Task: Have students release a yo-yo from rest, calculate its acceleration from distance and time measurements, and then determine the yo-yo's rotational inertia (requires the yo-yo's mass and the radius at which the string connects to the yo-yo). Next, have them roll the yo-yo down a ramp and use distance and time data to construct a conservation of energy equation that can be solved for the yo-yo's rotational inertia.
3. Concept-Oriented Demonstration
   Obtain a ring and a disk of equal mass and radius, and load up a low-friction cart with weights to make it the same mass. "Race" the three objects from rest down identical inclines to show students the cart wins, then the disk, and then the ring. Have students explain why, with forces and then with energy.
4. Ranking: A wheel rolls down an incline from rest and across a flat surface.
   a. Case 1: Tracks are rough enough that there is no slipping.
   b. Case 2: Tracks have some friction, but there is slipping.
   c. Case 3: Tracks have negligible friction. Have students rank translational kinetic energies at
   d. the end, rotational kinetic energies at the end, and total mechanical energies of the wheel at the end as three separate tasks.

RESOURCES

Teacher Resources:

- https://apcentral.collegeboard.org/pdf/ap-physics-1-curriculum-module-2015.pdf?course=ap-physics-1
- https://apcentral.collegeboard.org/pdf/physics-conservation-concepts.pdf?course=ap-physics-1
- https://apcentral.collegeboard.org/courses/resources/ap-physics-1-and-2-inquiry-based-lab-investigations?course=ap-physics-2

Equipment Needed:

- Laptop connection for power point presentations
- Laboratory equipment as specified for unit