ROBBINSVILLE PUBLIC SCHOOLS

OFFICE OF CURRICULUM AND INSTRUCTION

SCIENCE:

PHYSICS

Curriculum Writing Committee

Megan N. Correia

*Adapted from State of NJ Model Curriculum, & Aligned with NGSS

Supervisors

Ms. Molly Avery
Ms. Nicole Rossi

BOARD OF EDUCATION INITIAL ADOPTION DATE:

Robbinsville Public School District's
Mission Statement

The mission of the Robbinsville School District is to prepare today's students to successfully meet the challenges of tomorrow.

Robbinsville High School's Mission Statement

Robbinsville High School of Mercer County, is a community of diverse students, involved parents, and dedicated professionals devoted to lifelong learning.

Our mission is to provide academically challenging and technologically advanced small-learning environments that foster the development of young adults as responsible, respectful, and successful contributors to a global society.

Course Philosophy

The Robbinsville School District Science Department has taken the approach to teach physics first as physics is the foundation for all science. Developmentally, students in ninth grade will find that physics is the easiest science to observe through experimentation. Students will apply their algebra-based math skills in real situations and build the problem solving skills needed for chemistry. With a foundation of physics and chemistry courses students will be ready for biology which can be related to the concepts of chemistry and physics. It is the desire of the science department to create not only a more scientifically literate community, but to generate excitement and interest for their students and produce more positive attitudes towards science.

Course Description

Physics is a laboratory-based course covering the topics of metric conversion, measuring, kinematics, dynamics, energy, power, waves, sound, and light. This course is designed to provide students with hands-on, direct experiences and opportunities to inquire into relevant physics concepts. It provides a knowledge base in physics for all students by requiring students to engage in higher order thinking creating a foundation for chemistry and biology.

Course Materials:

May include, but are not limited to, the following:

- Conceptual/ CP - Hewitt Conceptual Physics textbook and supporting resources
- Honors - Glencoe Physics: Principles and Problems
- Physicsclassroom.com
- NJCTL materials
- PHET interactive simulations
- student -designed lab investigations
- teacher -created POGILS

Major Categories of Physics

ABOUT SCIENCE
Introduction to Physics
Investigation & Laboratory Design
Measurement & Metric System

MECHANICS
Linear Motion
Newton's First Law of Motion: Inertia
Newton's Second Law of Motion: Force and Acceleration
Newton's Third Law of Motion: Action and Reaction
Free Fall/ Gravity/ Projectile and Satellite Motion
Universal Gravitation
Momentum
Work, Power, Energy
Circular Motion
Rotational Motion

WAVES
Vibrations and Waves
Longitudinal and Transverse Waves
Wave properties and Motion

SOUND
Sound Waves
Frequency, Wave Speed
Musical Sounds

LIGHT
Properties of Light & Light Waves
Color
Reflection and Refraction

UNIT 1: ABOUT SCIENCE

Approx. 10 class periods

Introduction to Physics
Investigation & Laboratory Design
Measurement & Metric System

Stage 1 – Desired Results
Performance Expectations: This introductory unit serves a vital purpose in establishing a scientific culture & community among students in physics. For 9th graders, a successful middle-to-high school transition is of paramount importance in a student's future high school career, and as such, this unit focuses on establishing a proper scientific culture and conceptual framework for the remainder of the course. Additionally, the metric system will be taught. Since the year 2000, all European Countries are accepting 'metric only' labeling on products. Therefore, it is critical that the Unites States (companies, consumers, teachers, and students) embrace and use the metric system for measurement, in order to remain globally aware and relevant. ● Analyze the pros and cons of both English and metric systems while debating the hypothetical implementation of one universal measurement system worldwide ● Accurately convert both metric & standard units (Ladder Method & Dimensional Analysis), and apply conversions to real world scenarios (ie., cosmetic & toiletry products, recipes, etc.) ● Design & model multiple ways of experimental design, data collection & organization, and experimental design revision ● Construct & effectively communicate evidence-based claims **Related Problems / Possible Phenomena:** Why did the Mars Climate Orbiter crash? Students will engage in an research & debate based investigation to determine why this very expensive piece of space equipment crashed and ultimately determine that it was due to teams using different units of measurement without converting to a common unit. This will segue into the aforementioned debate on metric vs. standard units. AS a hook to the concept that motion is relative, can show images such as: https://www.ngssphenomena.com/#/who-moves-sky-or-us/
Standards to be addressed: **ELA**: ● CCSS.ELA-LITERACY.RST.9-10.1: Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. ● CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas 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. ● CCSS.ELA-LITERACY.RST.9-10.8: Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem ● CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.

Mathematics:

- 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.1**
- Define appropriate quantities for the purpose of descriptive modeling. **HSN.Q.A.2**
- Interpret expressions that represent a quantity in terms of its context. **HSA.SSE.A.1**
- Reason abstractly and quantitatively. **MP.2**
- Model with mathematics. **MP.4**

Enduring Understandings / Big Ideas	Problem(s) / Essential Questions
Students will understand that: • In any laboratory design, claims are investigated, evidence is analyzed & interpreted, and reasoning is data- & observation-driven • Unit conversion, both standard & metric, is vital in terms of a common scientific language and global perspective	• Should the entire world use one, universal system of measurement? • How can I design the best possible device to protect an egg within the given design / time constraints & parameters? • How can questions be framed / modeling occur to drive a solid laboratory design?

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
• Asking Questions • Planning and carrying out investigations: Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. • Analyzing and interpreting data - Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.	• HS-PS2 - Motion and Stability: Forces and Interactions: applied informally when designing the egg drop device; students will dig deeper into the PSI in future units • HS-ETS1 - Engineering Design: students will begin to explore the engineering design loop	1. Patterns 2. Cause and effect 3. Scale, proportion, and quantity 4. Systems and system models.

Stage 2 – Assessment Evidence	
Performance Task(s) ● Metric Olympics - students will engage in a competition involving both measurement predictions and unit conversions with standard and metric units. Data is based off student design. Assessment will be based on not necessarily accurate prediction, but ability to explain reasoning behind predictions and then construct a claim based on data collected. ● Egg drop - students will have design constraint parameters and a time limit to construct a device that will protect and egg when dropped from ceiling height. Although students do not yet have the physics conceptual framework (impulse, momentum, energy, etc.) to fully explain their design, this will serve as a vital piece of the engineering design loop mentality. Students will explain their rationale behind their design prior to dropping the egg, and will continue to revisit and revise their design throughout the year based on new concept attainment. ● As a formative assessment, students will utilize the Claim Evidence Reasoning (CER) framework to explain the details behind their design process and will self evaluate and peer evaluate using the CER rubric to gain familiarity with the framework, as this serves as a basis for the thought processes behind the NGSS framework ● Metric Patrol Project - students will dig through products at home and in stores with the goal of finding product labels that are not using the metric system correctly. Then, they will write business letters to the company, identifying the problem and offering a solution.	**Other Evidence:** ● Daily “clicker” formative assessment to gauge student understanding of concepts - teacher will adjust subsequent lessons as needed, based on this data. Students will be able to collaborate in groups and respond individually via their devices ● Group based lab & Peer Oriented Guided Inquiry Learning (POGIL) approach: ● Whole class discussion & teacher check-ins during collaborative group learning ● Individual assessment at end of unit ● In addition to any aforementioned differentiation at the Honors level, honors students will be expected to analyze more primary sources, will be assessed in align with higher standards set forth in rubrics, will be assessed on more complex mathematical and conceptual applications, and will engage in more self-directed exploration and learning.

Stage 3 – Learning Plan

Learning Activities:
Please see activities & assessments mentioned above. Daily class activities will include some sort of hook to begin the lesson, followed by a whole class engagement activity. The majority of the learning experiences in the unit will be student designed so as to expose students to the framework of NGSS. Students will have opportunities to engage in the engineering design loop, create and answer questions, make predictions, collect and analyze data, and construct evidence based claims. Students will also have guided practice in proper measurement and unit conversion techniques, with opportunities to demonstrate their learning through lab investigations. Differentiation and scaffolding as needed for learners not meeting, or exceeding, performance expectations.

Technology and the Nature of Science:
The metric system is the 'language' of science. As future participants in a global society, familiarity with this language is essential to working within not just science and tech fields, but global markets. For example, in 1999, NASA's MArs climate orbiter (worth over $100 million) crashed due to a mathematical error between two teams working on the equipment: the Lockheed Martin engineering team used English units of measurement, while the NASA's team used the metric system - a costly example of what can happen when one fails to engage in the common language of metrics. Additionally, data consumption & storage capacity is measured using metric prefixes (e.g., megabyte, terabyte)\, etc.), so students should have a working understanding of these prefixes to be knowledgeable consumers in society.

Know-What are the basics?:
Students should become familiar with the terminology of NGSS in this unit, such as the language behind the DCI's, cross-cutting concepts, and practices. Students also should know the basic metric units (meters,liters, grams) and prefixes (kilo, hecto, deka, deci, centi, milli)

Possible Preconceptions/Misconceptions:
As the introduction to the metric system, students may have a preconceived notion that standard measurements used in the United States are 'better than' the metric system. This misconception is due only to familiarity - one of the goals of this unit is to allow students opportunities to engage in the metric system through making predictions and collecting / converting metric data via activities such as the Metric Olympics.

How do I reinforce or build literacy or mathematics skills?
The CCSS in Mathematics are demonstrated within unit conversions in the activities described above. The CCSS in ELA is demonstrated when students are encouraged to write throughout many formative assessments both in Laboratory Reports, Claims, Evidence, and Reasoning (CER), portfolios, reflections, and descriptions.

UNIT 2: LINEAR MOTION & NEWTON'S LAWS

Approx. 30 class periods

Speed, Velocity, Acceleration
Newton's First Law of Motion: Inertia
Newton's Second Law of Motion: Force and Acceleration
Newton's Third Law of Motion: Action and Reaction

Stage 1 – Desired Results
Performance Expectations: We intuitively rely on motion concepts every day - when we walk, exercise, drive etc. While we conceptually view motion on a daily basis, motion is mathematically studied through kinematics, which is the study of how things move. The study of kinematics is the foundation for this physics course and future possible physics courses; students will study motion on a simplified, idealized scale (i.e., one dimension, in the absence of friction, etc.). This simplified investigation of kinematics is essential so that students can obtain a firm understanding of the basis of kinematics. Once mastered, students can apply their knowledge to the more complex real world situations in future units of study. In this unit of study, students are expected to *plan and conduct investigations*, *analyze data and using math to support claims*, and *apply scientific ideas to solve design problems* students in order to develop an understanding of ideas related to why some objects keep moving and some objects fall to the ground. Students will also build an understanding of forces and Newton's second law. The crosscutting concepts of *patterns*, *cause and effect*, and *systems and systems models* are called out as organizing concepts for these disciplinary core ideas. Students are expected to demonstrate proficiency in *planning and conducting investigations*, *analyzing data and using math to support claims*, and *applying scientific ideas to solve design problems* and to use these practices to demonstrate understanding of the core ideas. Students enrolled in an honors course will explore the additional 2-dimensional components of projectile motion, utilizing basic trigonometric concepts to make predictions about the motion (displacement, velocity, & acceleration) of an object in as it travels in a parabolic path. **Performance Expectations May Include:** ● Given a graph of position or velocity as a function of time, recognize in what time intervals the position, velocity and acceleration of an object are positive, negative, or zero and sketch a graph of each quantity as a function of time. *[Clarification Statement: Students should be able to accurately move from one representation of motion to another.]* (PS2.A) **Emphasis placed on this PE in Honors classes; Honors students will be expected to meet this PE both mathematically and conceptually, while CP students will be expected to model more conceptually* ● Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. (PS2.A) **Emphasis placed on this PE in Honors classes; Honors students will be expected to meet this PE both mathematically and conceptually, while CP students will be expected to model more conceptually* ● Understand and apply the relationship between the net force exerted on an object, its inertial mass, and its acceleration to a variety of situations. (PS2.A) **Emphasis placed on this PE in Honors classes; Honors students will be expected to meet this PE both mathematically and conceptually, while CP students will be expected to model more conceptually* ● Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. *[Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time*

for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at nonrelativistic speeds.] (HS-PS2-1)

Related Problems / Possible Phenomena:

- Students will explore data to generate conclusions about various braking distances and stopping times associated with varying speeds, and the timing behind yellow traffic lights
- Honors student exploring projectile motion will be asked to develop an explanation as to why an object launched horizontally hits the ground at the same time as an object dropped vertically (from the same height).
- Students will explore how an object changes speed as it falls through the atmosphere (i.e. what factors affect terminal velocity)
- Students will be asked to make predictions about, and then construct explanation as to why, the following demos occur:
    - Newton's Laws Demos: Plate & Tablecloth - table cloth is pulled from under a stack of plates; what happens?
    - Apple & Knife - an apple is placed on top of a knife, and the whole system is slammed on the desk - what happens?
    - Nickel & Knife - a stack of nickels is placed on a table, and a knife must be used to remove only the bottom nickel - how is this accomplished?
    - Phenomena also include the following links:
        - https://www.youtube.com/watch?v=d8IwevSFtV4
        - https://youtu.be/AEPvSo8bE2I
        - https://plus.google.com/102786751626732213960/posts/RUonc7qfaPt
        - https://www.ngssphenomena.com/#/sleddinginertia/
        - https://www.youtube.com/watch?v=BLuI118nhzc

Standards to be addressed:
ELA:

- WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
- WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- WHST.9-12.9 Draw evidence from informational texts to support analysis, reflection, and research.

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).

Enduring Understandings / Big Ideas	Problem(s) / Essential Questions

• Speed, velocity, and acceleration are different but related quantities that depend on the motion and position of an object
• Motion can be represented in a variety of data formats (graphs, observations, etc.), and can be used to describe and predict the future motion of an object.
• Students can use their motion data to:
  ○ interpret given motion data to predict the behavior of moving objects
  ○ Generate, analyze, and express self-generated motion data
  ○ develop written explanations to describe the motion of objects
  ○ distinguish between objects moving at constant velocity (zero acceleration) and changing velocities (acceleration)
• Students will be able to analyze and categorize real world scenarios according to Newton's 3 Laws of motion, both conceptually and mathematically
	• Why do I feel like I'm being tossed forward when a car brakes?
	• Why do I feel like I'm being pinned back when a roller coaster starts?
	• How do headrests in cars help to protect passengers from neck injuries if their car is rear-ended?
	• Why is it important to wear your seatbelt in a car?
	• Why is it more difficult to push an object across a bumpy surface, than across ice?
	• How does a car's velocity relate to the distance it needs to stop?
	• Why do dull knives not work as well?
	• Why do high heels sink into mud, but sneakers aren't as likely to?

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (HSPS2-1) Using Mathematics and Computational Thinking • Use mathematical representations of phenomena to describe explanations. (HS-PS2- 2)	PS2.A: Forces & Motion • Newton's second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1) • Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. ETS1.A: Defining and Delimiting Engineering Problems • Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation	Cause and Effect • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2-1) Systems and System Models • When investigating or describing a system, the boundaries and initial conditions of the

Constructing Explanations and Designing Solutions • Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects. (HSPS2-3) • Design a solution to a complex real world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2) • Evaluate a solution to a complex real world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary to HS-PS23) • ETS1.C: Optimizing the Design Solution • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade offs) may be needed. (secondary to (HS-PS2-3) • ETS1.B: Developing Possible Solutions • When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)	system need to be defined. (HS-PS2-2)

Stage 2 – Assessment Evidence

Performance Task(s)	Other Evidence:
● Students will select appropriate tools and collect relevant laboratory data in order to conceptually, mathematically, and graphically describe the motion of given objects. **Emphasis placed on this PT in Honors classes; Honors students will be expected to meet this PE both mathematically, graphically, and conceptually, while CP students will have an emphasis on modeling conceptually* ● Students will generate graphs of motion from observable data (of their own experimental design) to model their motion as the jog, walk, skip, etc. through a certain distance of their choosing. This can include constructing position-time, velocity-time, and/or acceleration-time graphs based on laboratory data ● Students will create meaning of Newton's 1st law through a carousel of demos in which they will generate the law based on their observable data. ● Students will utilize experimental data to confirm Newton's 2nd Law; this may include using accelerometers to measure acceleration. ● Students will construct and analyze models (diagrams, mathematical models, graphs, lab data, etc) in regards to force, mass, and acceleration, in order to predict motion and changes in motion ● Students will create lab designs to model and investigate Newton's 3rd law, such as: rubber band / mousetrap cars, balloon rockets, fan cars, marble collisions, etc. ● Students will be able to discuss, interpret, and apply Newton's 3 laws. ● All rubrics will be designed to correlate with performance expectations and will be differentiated based on the level of the class. ● Students in Honors Classes will design a ramp and a means of data collection, utilizing lab technologies of their choosing, to predict the path of a marble being launched off their ramp. Parameters will include the marble not actually being able to leave the ramp before final calculation/data-based prediction is made for landing point. The problem surrounding this will be framed through a PBL of the teacher's choosing, and the lab analysis will take place through a CER assessment.	● Other activities can include: ○ Student-produced motion graphs graphs by walking towards or away from motion detectors ○ Ticker tape diagram analysis ○ PHET Online Lab: The Moving Man (Constant Velocity vs. Acceleration) ○ Measure 'g' using spark timers, photogates, motion detector, etc. ● Daily "clicker" formative assessment to gauge student understanding of concepts - teacher will adjust subsequent lessons as needed, based on this data. Students will be able to collaborate in groups and respond individually via their devices ● Group based lab & Peer Oriented Guided Inquiry Learning (POGIL) approach: POGIL utilizing the Newton's Laws activities; Car and Ramp Lab ● Whole class discussion & teacher check-ins during collaborative group learning ● Individual assessment at end of unit ● In addition to any aforementioned differentiation at the Honors level, honors students will be expected to analyze more primary sources, will be assessed in align with higher standards set forth in rubrics, will be assessed on more complex mathematical and conceptual applications, and will engage in more self-directed exploration and learning.

Stage 3 – Learning Plan
Learning Activities: Please see activities & assessments mentioned above. Daily class activities will include some sort of hook to begin the lesson, followed by a whole class engagement activity. The majority of the learning experiences in the unit will be student designed so as to expose students to the framework of NGSS. Students will have opportunities to engage in the engineering design loop, create and answer questions, make predictions, collect and analyze data, and construct evidence based claims. Differentiation and scaffolding as needed for learners not meeting, or exceeding, performance expectations. This unit will begin with an investigation into various types of forces. Students will explore types of forces and model them conceptually and mathematically through vector diagrams. Students will explore Newton's Laws via carousel demos and laboratory designs. Students will generate their own motion data, and use analyze it as a means of formulating conceptual and mathematical understanding of kinematics. The car and ramp setup may also be used as a means of collecting additional motion data and analyzing it in terms of acceleration. The culminating demonstration of proficiency will lie in generating and analyzing data to support Newton's 2nd law both conceptually and mathematically, and therefore the corresponding kinematics that align with Newton's Laws, such as displacement, velocity, and acceleration. Additionally, Honors students will engage in the marble-ramp projectile motion PBL as well as investigate coefficients of friction on flat surfaces and inclined planes. The parameters surrounding these activities may vary based on student choice and learning progressions. There will be a guided discussion before and after all lab activities. Students will be grouped into cooperative lab groups and given time to experiment and play with the lab activities. Differentiation will occur by student grouping and more/less teacher guidance and assistance when necessary. Higher groups will be given less guidance and more opportunity to explore scenarios and create their own questions, such as, "If I add more weight to the car, what will happen as it slides down the ramp?" etc. Other groups may need more prompting and guidance to create these questions. Data will be collected using technology and lab design of student's' choosing. Students who understand the concepts in the learning plan will be able to: ● Generate, analyze, and express data in a variety of modes to make claims about the motion of an object. ● Analyze data using tools, technologies, and/or models of their choosing & design, to support the claim that Newton's 2nd Law of motion describes the relationship among the net force on a macroscopic object, its mass, and its acceleration. Students will be able to model the relationship between Newton's Laws both mathematically and conceptually. **Technology and the Nature of Science:** *Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena* ● Theories and laws provide explanations in science. (HS-PS2-1),(HS-PS2-4) ● Laws are statements or descriptions of the relationships among observable phenomena. (HS-PS2-1),(HS-PS2-4) **Possible Preconceptions/Misconceptions:** Students tend to think of forces as being active (e.g, a push or pull) rather than passive (e.g., a support force). Additionally, students tend to believe that moving objects require a force to stay in motion; this, in fact, is only

the case in the presence of friction, which itself is a force. It is imperative that teacher provide intentional opportunities for modeling and questioning multiple scenarios to demonstrate the variety of forces that exist in the macroscopic world.

Misconceptions taken from AAAS Project 2061

- A constant force is needed to keep an object moving at constant speed.
- A force is required to keep an object moving. Objects slow down and stop if a force is not maintained (Sadanand & Kess, 1990; Twigger et al., 1994; Jung, 1981; Champagne et al., 1980; Watts, 1983; Osborne, 1985).
- Moving objects stop when they run out of force (Twigger et al., 1994).
- An object's force can be used up and must be replenished to maintain activity (Watts, 1983).
- A moving object has a force within it that keeps it moving (McCloskey, 1983; Osborne, 1985; Viennot, 1979).

How do I reinforce or build literacy or mathematics skills?

The CCSS in Mathematics are demonstrated within the learning plans using graphing to interpolate and extrapolate given motion data, representing forces in diagrams or mathematically using appropriately labeled vectors, with the emphasis of these mathematical tools and the application of trigonometry at the honors level.

Students will:

- Represent the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration symbolically and manipulate the representative symbols. Make sense of quantities and relationships among net force on a macroscopic object, its mass, and its acceleration.
- Use a mathematical model to describe how Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. Identify important quantities representing the net force on a macroscopic object, its mass, and its acceleration and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use units as a way to understand how Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. Choose and interpret units consistently in Newton's second law of motion, and choose and interpret the scale and origin in graphs and data displays representing the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
- Define appropriate quantities for the purpose of descriptive modeling of Newton's second law of motion

The CCSS in ELA is demonstrated when students are encouraged to write throughout many formative assessments both in Laboratory Reports, Claims, Evidence, and Reasoning (CER), portfolios, reflections, and descriptions.

Students will:

- Cite specific textual evidence to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
- Integrate and evaluate multiple sources of information presented in diverse formats and media in order to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
- Draw evidence from informational texts to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

UNIT 3: CONSERVATION

Approx. 25 class periods

Momentum

Work, Power, Energy

Stage 1 – Desired Results
Performance Expectations: In this unit of study, students will *plan and conduct investigations*, *analyze data and using math to support claims*, and *apply scientific ideas to solve design problems* students in order to develop their understanding of conservation of momentum: that the net momentum of a system is conserved when there is no net force on the system. Students are also able to apply science and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision (such as an egg drop). The crosscutting concepts of *patterns*, *cause and effect*, and *systems and systems models* are called out as organizing concepts for these disciplinary core ideas. Students are expected to demonstrate proficiency in *planning and conducting investigations*, *analyzing data and using math to support claims*, and *applying scientific ideas to solve design problems* and to use these practices to demonstrate understanding of the core ideas. Additionally, students will *develop and use models, plan and carry out investigations, use computational thinking and design solutions* as they make sense of *energy*. Students will explore the different *types of energy* and their relationships to each other, as well as relate *conservation of energy* to the previous concept of conservation of momentum. Students will tie these concepts together through and *energy transfer*, and *the relationship between energy and forces*. Energy is understood as a quantitative property of a system that depends on an object's motion or position, and the total change of energy in any system is equal to the total energy transferred into and out of the system. Students can also demonstrate their understanding of engineering principles when they design, build, and refine devices associated with the conversion of energy. The crosscutting concepts of *cause and effect, systems and systems models, energy and matter, and the influence of science, engineering, and technology on society and the natural world* are further developed in the performance expectations. Students are expected to demonstrate proficiency in *developing and using models, planning and carry out investigations, using computational thinking and designing solutions*, and they are expected to use these practices to demonstrate understanding of core ideas. **Performance Expectations May Include:** ● HS-PS2-2: Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. ● HS-PS2-3: Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision ● HS-PS3-2:Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). ● Identify and quantify the various types of energies within a system of objects in a well-defined state, such as elastic potential energy, gravitational potential energy, kinetic energy, and thermal energy and represent how these energies may change over time. (PS3.A and PS3.B) ● Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the

energies in gravitational, magnetic, or electric fields.] (HS-PS3-1)

- Calculate changes in kinetic energy and gravitational potential energy of a system using representations of that system.
- Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). *[Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]* (HS-PS3-2)
- Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. *[Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]* (HS-PS3-1)
- Honors students will be expected to meet the following PE: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.* [Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency. Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.] (HS-PS3-3)

Related Problems / Possible Phenomena:

- Insulating and conducting blocks - why does ice melt faster on the ‘cold’ block?
- https://www.ngssphenomena.com/#/woodpecker-slowmo/
- https://www.ngssphenomena.com/#/exploding-seeds/

Standards to be addressed:

ELA:

- CCSS.ELA-LITERACY.RST.9-10.1: Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
- CCSS.ELA-LITERACY.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.
- CCSS.ELA-LITERACY.RST.9-10.8: Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.
- CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.
- CCSS.ELA-LITERACY.WHST.9-10.7: Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- CCSS.ELA-LITERACY.WHST.9-10.9: Draw evidence from informational texts to support analysis, reflection, and research.

Mathematics:

- 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.1
- Define appropriate quantities for the purpose of descriptive modeling. HSN.Q.A.2
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. HSN.Q.A.3
- Interpret expressions that represent a quantity in terms of its context. HSA.SSE.A.1
- Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. HSA.SSE.B.3
- Create equations and inequalities in one variable and use them to solve problems. HSA.CED.A.1
- Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. HSA.CED.A.2
- Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. HSA.CED.A.4
- Graph functions expressed symbolically and show key features of the graph, by in hand in simple cases and using technology for more complicated cases. HSF-IF.C.7 15
- Represent data with plots on the real number line (dot plots, histograms and box plots). HSS-IS.A.1
- Reason abstractly and quantitatively. MP.2
- Model with mathematics. MP.4

Enduring Understandings / Big Ideas

Students will understand:

- The total momentum in a closed system does not change; it is conserved. (i.e., net initial momentum = net final momentum)
- Momentum is a vector quantity, with a direction that corresponds with its velocity
- impulse is a vector quantity, with a direction that corresponds with its causing force
- Concepts of momentum and impulse can be applied to real world examples, such as to collisions or explosions.
- The proportional relationships between work, force and displacement.
- The relationships between work and the various energy types
- The law of conservation of energy and how it relates to the concepts of work, kinetic energy, potential energy, and thermal energy, including the transfer of energy through a system due to heat, sound and/or light.
- Describe and apply the concepts of work and power, as well energy concepts of efficiency, to everyday situations.

Problem(s) / Essential Questions

- How does the concept of momentum and its conservation impact the design process for safety devices, such as those present in cars?
- How do we know something has energy?
- How can the effects of energy transfer be utilized to design more efficient devices?
- How has our understanding of work, energy and heat impacted the development of modern technology?

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts

Developing and Using Models • Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS3-2) Using Mathematics and Computational Thinking • Create a computational model or simulation of a phenomenon, designed device, process, or system. (HS-PS3-1) • Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4) Constructing Explanations and Designing Solutions • Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-PS3-3) Asking Questions and Defining Problems • Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1) Constructing Explanations and Designing Solutions • Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of	PS3.A: Definitions of Energy • Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (HS-PS3-2) • At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) • These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2) PS3.B: Conservation of Energy and Energy Transfer • Conservation of energy means that the total change of energy in any system is always equal to the total	Systems and System Models • Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. (HS PS3-1) • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. (HS-ETS1-4) Energy and Matter • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS PS3-3) • Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. (HS-PS3-2)

evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2) • Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	energy transferred into or out of the system. (HS-PS3-1) • Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1) • Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (HS-PS3-1) • The availability of energy limits what can occur in any system. (HS-PS3-1) PS3.D: Energy in Chemical Processes • Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3) ETS1.A: Defining and Delimiting Engineering Problems • Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary to HS-PS3-3)	

	• Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1) • Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HSETS1-1) ETS1.B: Developing Possible Solutions • When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3) • Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4) ETS1.C: Optimizing the Design	

	Solution • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)	

Stage 2 – Assessment Evidence

Performance Task(s)	Other Evidence:
- Develop a model that distinguishes between elastic and inelastic collisions. Model examples can include: online simulation (PHET, Walter-Fendt, etc.), physical collision cars & track with varying masses, etc. Students should have choice in designing their model, which will be used to predict the change in momentum of an object from the average force applied and the time during which the force is exerted, as well as predicting other aspects of the collision. Rubric will be designed to correlate with performance expectations and will be differentiated based on the level of the class. - Apply scientific and engineering ideas to design, evaluate and refine a device that minimizes the force on a macroscopic object during a collision. This could include a revision of the first unit's egg drop, which would allow students to engage in the engineering design loop & revision process. Rubric will be designed to correlate with performance expectations and will be differentiated based on the level of the class. - Muscle Up Lab -- students will design and investigation into their own energy expenditures and power outputs with various exercises and everyday activities - Analyze and model the energy transfers that take place in the functioning of a variety of toys. Rubric will be designed to correlate with performance expectations and will be differentiated based on the level of the class. - Possible extension: Devise a model that would explain an explosion. - Possible extension:Create a mathematical model of momentum of a moving body. - Possible extension: devise an experiment to calculate the value of ***g*** - Possible extension: devise an experiment to calculate the value of ***k*** in various springs, and analyze how different spring constants are used in designing everyd - Extension for students in Honors Classes: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy, i.e. Rube Goldberg machine	- Daily "clicker" formative assessment to gauge student understanding of concepts - teacher will adjust subsequent lessons as needed, based on this data. Students will be able to collaborate in groups and respond individually via their devices - Group based lab & Peer Oriented Guided Inquiry Learning (POGIL) approach: - Whole class discussion & teacher check-ins during collaborative group learning - Individual assessment at end of unit - In addition to any aforementioned differentiation at the Honors level, honors students will be expected to analyze more primary sources, will be assessed in align with higher standards set forth in rubrics, will be assessed on more complex mathematical and conceptual applications, and will engage in more self-directed exploration and learning.

Stage 3 - Learning Plan

Learning Activities:

Please see activities & assessments mentioned above. Daily class activities will include some sort of hook / phenomena / activating event to begin the lesson, followed by a whole class engagement activity. The majority of the learning experiences in the unit will be student designed so as to expose students to the framework of NGSS. Students will have opportunities to engage in the engineering design loop, create and answer questions, make predictions, collect and analyze data, and construct evidence based claims. Students will also have guided practice in proper measurement / unit conversion techniques, as well as data analysis, with opportunities to demonstrate their learning through lab investigations. Differentiation and scaffolding as needed for learners not meeting, or exceeding, performance expectations.

This unit will build on the previous unit's concepts of Newton's Laws and Kinematics. As students expand on their learning of Newton's 3rd Law, they will formulate the concepts behind the Law of Conservation of Momentum (e.g., 2 people on scooters push off each other; how does the total momentum before collision compare with the total momentum after?). As students participate in various investigations, they should be provided with opportunities to derive the momentum formula based on their observations. From that, they should further derive the impulse-momentum change theorem. These formulas should not be introduced as rote-equations by the teacher prior to investigation; rather, students should be provided with a variety of hands-on activities and modeling opportunities designed to challenge their misconceptions and allow them to conceptualize the laws behind these formulas on their own, with the goal of students self-generating the formulas based on their learning activities. Students should use these models to make valid claims about, and predict changes in, the motion of objects

UNIT 4: ROTATION & GRAVITY

Approx. 15 class periods

Circular Motion; Rotational Motion
Free Fall/ Gravity/ Projectile and Satellite Motion
Universal Gravitation
Center of Gravity; Torque and Rotational Inertia Extension for Honors Students

Stage 1 – Desired Results
Performance Expectations: In this unit of study, students will explore phenomena to create meaning behind the centripetal force requirement. They will extend their learning to plan and conduct investigations and apply scientific ideas to make sense of Newton's law of gravitation. They apply this law to describe and predict the gravitational forces between objects. The crosscutting concept of *patterns* is called out as an organizing concept for this disciplinary core idea. Students are expected to demonstrate proficiency in *planning and conducting investigations* and *applying scientific ideas* to demonstrate an understanding of core ideas. Students also *use mathematical and computational thinking* to examine the processes governing the workings of the solar system and universe. The crosscutting concepts of *scale, proportion, and quantity* are called out as organizing concepts for these disciplinary core ideas. Students are expected to demonstrate proficiency in *using mathematical and computational thinking* and to use this practice to demonstrate understanding of core ideas. Finally, students will explore the effects of rotation as they apply to toppling objects, with an emphasis on center of gravity. Honors students will extend this concept by exploring the conceptual and mathematical applications of torque and rotational inertia. Performance Expectations may include: ● Apply Newton's 2nd Law to objects in uniform circular motion; from 2nd Law, derive the centripetal force equation and apply it to predict unknown variables in cases of circular motion ● Conceptually and mathematically analyze the proportional relationship between period, orbital radius, and speed of an object in circular motion and apply the circular velocity and angular speed equations to predict future quantities ● Calculate the gravitational force two objects exert on each other, and use it to predict planetary motion. ● Use Newton's Universal Law of Gravitation to derive the acceleration due to gravity for the surface of the Earth and for the surfaces of other planets ● Extension for students in Honors classes: Use mathematical and conceptual representations of Kepler's Third Law to analyze orbital radii, periods, etc. ● Use mathematical representations of Newton's Law of Gravitation to describe and predict the gravitational and forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational fields.] [Assessment Boundary: Assessment is limited to systems with two objects.] (HS-PS2-4) ● Use mathematical or computational representations to predict the motion of orbiting objects in the solar system. [Clarification Statement: Emphasis is on Newtonian gravitational laws governing orbital motions, which apply to human-made satellites as well as planets and moons.] [Assessment Boundary: Mathematical representations for the gravitational attraction of bodies and Kepler's Laws of orbital motions should not deal with more than two bodies, nor involve calculus.] (HS ESS1-4) **Related Problems / Possible Phenomena:** Phenomena will include demo station activities, as well as the following links: ● https://www.ngssphenomena.com/#/jupiter-asteroids/ ● https://www.ngssphenomena.com/#/f22raptor-9g-turns/

- https://www.ngssphenomena.com/#/physics-escape/
- https://www.ngssphenomena.com/#/human-loop/
- https://www.ngssphenomena.com/#/new-gallery-2/
- Physics Classroom Tutorials: http://www.physicsclassroom.com/Class/index.cfm
- Ladybug Revolution: https://phet.colorado.edu/en/simulation/rotation
- Circular motion: http://www.wiley.com/college/halliday/0470469080/simulations/sim06/sim06.html
- Uniform circular motion: http://www.walter-fendt.de/ph14e/circmotion.htm
- Carousel: http://www.walter-fendt.de/ph14e/carousel.htm
- Circular motion: http://physics.bu.edu/~duffy/Ejs/EP_chapter05/circular_motion.html
- Classic circular force lab: http://www.thephysicsaviary.com/Physics/Programs/Labs/ClassicCircularForceLab/index .html
- Circular force lab: http://www.thephysicsaviary.com/Physics/Programs/Labs/CircularForceLab/index.html

Standards to be addressed:

ELA:
- CCSS.ELA-LITERACY.RST.9-10.1: Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
- CCSS.ELA-LITERACY.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.
- CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.
- CCSS.ELA-LITERACY.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.
- CCSS.ELA-LITERACY.WHST.9-10.8: Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- CCSS.ELA-LITERACY.WHST.9-10.9: Draw evidence from informational texts to support analysis, reflection, and research.

Mathematics:
- 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.1 19
- Define appropriate quantities for the purpose of descriptive modeling. HSN.Q.A.2
  Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. HSN.Q.A.3
- Interpret expressions that represent a quantity in terms of its context. HSA.SSE.A.1
- Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. HSA.SSE.B.3
- Create equations and inequalities in one variable and use them to solve problems. HSA.CED.A.1
- Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. HSA.CED.A.2
- Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. HSA.CED.A.4

- Graph functions expressed symbolically and show key features of the graph, by in hand in simple cases and using technology for more complicated cases. HSF-IF.C.7
- Represent data with plots on the real number line (dot plots, histograms and box plots). HSS-IS.A.1
- Reason abstractly and quantitatively. MP.2
- Model with mathematics. MP.4

Enduring Understandings / Big Ideas :	Problem(s) / Essential Questions
Students will understand that: • Centripetal forces and their corresponding accelerations are directed inward, and cause circular motion. There are many sources of centripetal forces, including friction and gravity. • The force of gravity is directly proportional to the product of the masses involved, and inversely proportional to the distance squared between their centers of gravity • An object will remain balanced if its center of gravity is aligned with its area of support (especially if its center of gravity is beneath is area of support). If the center of gravity is not aligned with the area of support, the object will experience and effect of rotation called torque, and will topple • Astronauts in the International Space Station still experience ~90% earth's gravity; they simply lack a support force as they are projectiles circling earth with a large enough tangential velocity to fall about earth, not into it.	• Why am I stuck on earth but astronauts are 'weightless' in space? • Why do I feel like there is a force tossing me outward when I make a turn? • Why is it easier to balance in certain scenarios? • Why do things orbit? (satellites orbit earth, planets orbit stars, etc.) • How do space agencies minimize fuel usage on missions and maximize acceleration due to gravity? • How is our understanding of the universe constantly changing?

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking • Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and	PS2.B: Types of Interactions • Newton's law of universal gravitation provides the mathematical model to describe and predict the effects of gravitational forces between distant objects. (HS-PS2-4) • Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause	Patterns • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS2-4) Scale, Proportion, and Quantity • Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth

model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Use mathematical representations of phenomena to describe explanations. (HSPS2-4) • Use mathematical or computational representations of phenomena to describe explanations. (HS-ESS1-4)	magnetic fields; electric charges or changing magnetic fields cause electric fields. (HS-PS2-4) ESS1.B: Earth and the Solar System • Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system. (HS-ESS1- 4)	vs. exponential growth). (HS-ESS1-4)

Stage 2 – Assessment Evidence	
Performance Task(s) • Centripetal Force discovery stations: students will carousel through a variety of stations and explore different phenomena with the same guiding question: in what direction does the force act? Students will unpack the centripetal force requirement through these stations and discover that contrary to popular misconceptions, the centripetal force that holds objects in a circular path acts inward. • Centripetal Force Lab: Students will generate and analyze data to discover the correlations between force, mass, velocity and radius for an object traveling in a circle. This data will be used to derive the centripetal force equation as well as conceptually and mathematically model the equations for speed and velocity • Possible extension: use above data in addition to research on the ***g*** forces a human can sustain to design an amusement park ride that meets both safety and thrill-seeking requirements. Create an advertising campaign for your thrill ride. Rubric will be designed to correlate with performance expectations and will be differentiated based on the level of the class. • ULOG PHET Gravity Force Lab: Visualize the gravitational force that two objects exert on each other. Adjust properties of the objects to see how changing the properties affect the gravitational attraction. Based on the data generated, create hypotheses about the orbital motion of other planetary objects. Test those hypotheses; analyze data through CER template • Travel brochure for astronomical object of student choosing: in the travel brochure, students will not only 'sell' their astronomical object as a travel destination, but also demonstrate proficiency in the conceptual and mathematical applications of Newton's Law of Universal Gravitation, Centripetal Force, and Kepler's Laws • Phenomena stations to explore	**Other Evidence:** • Daily "clicker" formative assessment to gauge student understanding of concepts - teacher will adjust subsequent lessons as needed, based on this data. Students will be able to collaborate in groups and respond individually via their devices • Group based lab & Peer Oriented Guided Inquiry Learning (POGIL) approach: • Whole class discussion & teacher check-ins during collaborative group learning • Individual assessment at end of unit • In addition to any aforementioned differentiation at the Honors level, honors students will be expected to analyze more primary sources, will be assessed in align with higher standards set forth in rubrics, will be assessed on more complex mathematical and conceptual applications, and will engage in more self-directed exploration and learning.

various ‘balancing acts’ with the goal of students generating, based on qualitative data, the rule for balancing and toppling. Extensions for honors students will include quantitatively predicting the conditions necessary for a seesaw to balance, then testing their data and hypothesis via a torque balance	

Stage 3 - Learning Plan

Learning Activities:

Please see activities & assessments mentioned above. Daily class activities will include some sort of hook / phenomena / activating event to begin the lesson, followed by a whole class engagement activity. The majority of the learning experiences in the unit will be student designed so as to expose students to the framework of NGSS. Students will have opportunities to engage in the engineering design loop, create and answer questions, make predictions, collect and analyze data, and construct evidence based claims. Students will also have guided practice in proper measurement / unit conversion techniques, as well as data analysis, with opportunities to demonstrate their learning through lab investigations. Differentiation and scaffolding as needed for learners not meeting, or exceeding, performance expectations.

Students will begin their learning progression by exploring the centripetal force requirement through stations, demos, and lab investigations. While the qualitative and quantitative applications are immediately available to everyday life experiences, the bigger focus in this unit is the the extension to universal gravitation. Students should be able to use the law of universal gravitation as a mathematical model to accurately describe and predict the effects of gravitational forces between distant objects. This should be done both qualitatively and quantitatively. In order to explain and predict interactions between objects and within systems of objects, students might be given data (e.g., mass, separation distance, radius of body, etc.) and asked to perform calculations to show how the force of gravity is dependent upon the mass of the bodies and the distance between two bodies. Students can also perform calculations to show how the acceleration due to gravity changes for different celestial bodies and is dependent upon the mass of the body and its radius. Students should examine data to observe patterns at different scales and to provide evidence for gravitational forces between two objects in a system with two objects. Data that students are given may include natural satellites, man-made satellites, planets, comets, and other astronomical objects. Students should also use the universal gravitation equation to verify the value of $9.8\ m/s^2$ as being the average acceleration due to gravity on Earth. In all calculations and data sets, students should choose and interpret units consistently in formulas and choose and interpret the scale and origin in graphs and data displays representing their findings. These experiences will allow students to observe and consequently provide evidence for gravitational forces between two objects in a system. The mathematical applications and relationships will be emphasized for students in the honors course.

Honors students will also explore Kepler's Laws and further analyze the motion of orbiting bodies both conceptually and mathematically. They will explore and derive the laws through computer simulation labs, modeling (such as creating ellipses with tacks, cardboard, and string), and mathematical models. They will apply their learning in a culminating PBL, such as designing a sales pitch and travel brochure to visit an astronomical object.

Students will further extend their learning through center of gravity stations, in which various balancing acts are performed. Based on successful and unsuccessful balancing attempts, students should generate the conceptual framework of toppling: that an object's center of gravity must be aligned with the area of support. This conceptual framework can be immediately applied to daily physical activities, sports, vehicles, etc. Honors students will further extend this concept through torque and rotational inertia, in which they will be required to make predictions about and design a balancing see-saw using various masses.

Possible Learning activities may include:

- PHET Planetary Orbits Lab - investigating and applying Kepler's laws of motion, as well as the effects of velocity and centripetal force, on a satellites' orbit
- PHET Gravity Force Lab - investigate the variables that affect the gravitational force between two objects; experimentally determine the quantitative value of G, the Universal Gravitational constant.
- NASA activity - Period of Jupiter's moons - Students analyze a series of images of Jupiter's 4 Galilean

moons to discover their orbital periods and orbit radii. They compare their results with data they research for those moons. Data is analyzed qualitatively and quantitatively to unpack the relationship between orbital period and orbital radius to derive Kepler's 3rd Law.

Students who understand the concepts are able to:

- Use mathematical representations of phenomena to describe or explain how gravitational force is proportional to mass and inversely proportional to distance squared.
- Demonstrate how Newton's Law of Universal Gravitation provides explanations for observed scientific phenomena.
- Observe patterns at different scales to provide evidence for gravitational forces between two objects in a system with two objects
- Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
- Use mathematical and computational representations of Newtonian gravitational laws governing orbital motion that apply to moons and human made satellites.
- Use algebraic thinking to examine scientific data and predict the motion of orbiting objects in the solar system

Technology and the Nature of Science:
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- Theories and laws provide explanations in science. (HS-PS2-4)
- Laws are statements or descriptions of the relationships among observable phenomena. (HSPS2-4)

Possible Preconceptions/Misconceptions:
Some misconceptions adapted from NSDL, 2015

- Objects moving in a circular path do not experience a force
- Objects moving in a circular path do not change velocity or accelerate
- Objects moving in a circular path 'want' to keep moving in a circular path, like Newton's Laws
- When traveling in a circular path, there is a force that pushes the object outward
- Earth orbits the sun because the sun exerts more gravity on the earth than the earth exerts on the sun
- Two objects of different mass exert different gravitational forces on each other
- Gravity is not a force
- Gravity is stronger above earth's surface
- Astronauts experience very little to zero earth gravity

How do I reinforce or build literacy or mathematics skills?
The CCSS in Mathematics are demonstrated are generally demonstrated through unit conversions and algebraic manipulation of formulas in the activities described above. The CCSS in ELA is demonstrated when students are encouraged to read, write, analyze, and peer review throughout many formative assessments, such as: Laboratory Reports, Claims, Evidence, and Reasoning (CER), portfolios, reflections, and descriptions.

Mathematics:

- Use symbols to represent Newton's law of gravitation and gravitational forces between two objects in a system. Make sense of quantities and relationships to describe and predict the gravitational forces between two objects in a system.
- Use a mathematical model of Newton's law of gravitation to predict the gravitational forces between two objects in a system. Identify important quantities representing the gravitational forces between two

objects in a system and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose. •

- Use units as a way to understand the gravitational and electrostatic forces between two objects in a system; choose and interpret units consistently in formulas representing Newton's law of gravitation, and gravitational forces between two objects in a system. Choose and interpret the scale and origin in graphs and data displays representing the gravitational forces between two objects in a system.
- Define appropriate quantities for the purpose of descriptive modeling of the gravitational forces between two objects in a system.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the gravitational forces between two objects in a system.
- Interpret expressions that represent quantities of the gravitational forces between two objects in a system in terms of their context.
- Choose and produce an equivalent form of an expression to reveal and explain properties of the gravitational forces between two objects in a system.
- Represent the motion of orbiting objects in the solar system symbolically, and manipulate the representing symbols. Make sense of quantities and relationships about the motion of orbiting objects in the solar system symbolically and manipulate the representing symbols.
- Use a mathematical model to explain the motion of orbiting objects in the solar system. Identify important quantities in the motion of orbiting objects in the solar system and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use units as a way to understand the motion of orbiting objects in the solar system and to guide the solution of multi step problems; choose and interpret units representing the motion of orbiting objects in the solar system consistently in formulas; choose and interpret the scale and the origin in graphs and data displays representing the motion of orbiting objects in the solar system.
- Define appropriate quantities for the purpose of descriptive modeling of the motion of orbiting objects in the solar system.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the motion of orbiting objects in the solar system.
- Interpret expressions that represent the motion of orbiting objects in the solar system.
- Create equations in two or more variables to represent relationships between quantities representing the motion of orbiting objects in the solar system; graph equations representing the motion of orbiting objects in the solar system on coordinate axes with labels and scales.
- Rearrange formulas representing the motion of orbiting objects in the solar system to highlight a quantity of interest, using the same reasoning as in solving equations.

UNIT 5: WAVES

Approx. 10 class periods

Vibrations and Waves
Longitudinal and Transverse Waves
Wave properties and motion
Sound Waves
Frequency, Wave Speed
Musical Sounds
Properties of Light & Light Waves
Color
Reflection and Refraction

Stage 1 – Desired Results
Performance Expectations: Waves are a means of transmitting energy, whether they are mechanical waves (such as sound), or electromagnetic waves (light). It is important to note that waves do not transmit material; however, mechanical waves need a material through which to travel (light does not). The applications of this unit are immediately applicable to daily life, as they govern what / why we hear and see. Students will learn about resonance, forced vibration, the doppler effect, reflection and refraction, electromagnetic radiation, and color. In this unit of study, students will be exposed to a variety of phenomena and will be asked to generate hypotheses as to why they are hearing / seeing what's in front of them. These hypotheses will be refined to conceptualize understanding of various properties of sound and light. Students will further apply their understanding of wave properties to make sense of how electromagnetic radiation can be used to transfer information across long distances, store information, and be used to investigate nature on many scales. The crosscutting concept of cause and effect is highlighted as an organizing concept for these disciplinary core ideas. Models of waves, both mechanical and electromagnetic, are developed and used. Students also demonstrate their understanding of engineering ideas by presenting information about how technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. The crosscutting concepts of systems and system models; stability and change; interdependence of science, engineering, and technology; and influence of engineering, technology, and science on society and the natural world are highlighted as organizing concepts. Students are expected to demonstrate proficiency in asking questions, engaging in argument from evidence, and obtaining, evaluating, and communicating information, and they are expected to use these practices to demonstrate understanding of the core ideas. Performance Expectations may include: ● Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. [Clarification Statement: Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.] (HS-PS4-1) ● Analyze and describe wave motion through various media ● Model and explain wave interference.

- Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other. [Clarification Statement: Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a phenomenon could include resonance, interference, diffraction, and photoelectric effect.] [Assessment Boundary: Assessment does not include using quantum theory.] (HS-PS4-3)
- Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. [Clarification Statement: Emphasis is on the idea that photons associated with different frequencies of light have different energies, and the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. Examples of published materials could include trade books, magazines, web resources, videos, and other passages that may reflect bias.] [Assessment Boundary: Assessment is limited to qualitative descriptions.] (HS-PS4-4)
- Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.* [Clarification Statement: Examples could include solar cells capturing light and converting it to electricity; medical imaging; and communications technology.] [Assessment Boundary: Assessments are limited to qualitative information. Assessments do not include band theory.] (HS-PS4-5)
- Evaluate questions about the advantages of using a digital transmission and storage of information. [Clarification Statement: Examples of advantages could include that digital information is stable because it can be stored reliably in computer memory, transferred easily, and copied and shared rapidly. Disadvantages could include issues of easy deletion, security, and theft.] (HS-PS4-2)

Related Problems / Possible Phenomena:

- Pennies from different years (pre/post 1982) make different sounds when dropped
- Two speakers angled at each other produce seemingly louder and softer sounds as one backs away from them
- A tuning fork struck, then held against a table, produces a louder sound
- Frequency range hearing test
- Light refracts through a prism
- A cup of water ‘bends’ a submerged pencil
- Polarizing filters overlapped at 90 degree angles block all light
- Magenta, yellow, cyan color filters overlapped block all light
- Red, green, blue spotlights overlapped produce white light
- ‘Mirage’ apparatus
- Concave and convex mirrors alter images and change the image at varying distances
- https://www.ngssphenomena.com/#/uv-sun-damage/
- https://www.ngssphenomena.com/#/camels-or-shadows/
- https://www.ngssphenomena.com/#/looking-through-water/
- Doppler ball -https://www.ngssphenomena.com/#/dopplereffect/

Standards to be addressed:

ELA:
- CCSS.ELA-LITERACY.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.
- CCSS.ELA-LITERACY.RST.9-10.8: Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.
- CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.
- CCSS.ELA-LITERACY.WHST.9-10.8: Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- CCSS.ELA-LITERACY.WHST.9-10.9: Draw evidence from informational texts to support analysis, reflection, and research.

Mathematics:

- Reason abstractly and quantitatively. (HS-PS4-1) MP.2
- Model with mathematics. (HS-PS4-1) MP.4
- Interpret expressions that represent a quantity in terms of its context. (HS-PS4-1) HSA-SSE.A.1
- Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. (HS-PS4-1) HSASSE.B.3
- Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. (HS-PS4-1) HSA.CED.A.4

Enduring Understandings / Big Ideas:	**Problem(s) / Essential Questions**:
Students will understand that: • Waves transfer energy through different mechanisms based on their wave type • Wavelength and frequency are inversely proportional; analyzing them determines the type of sound or light wave and its implications for humans and ability to explain natural phenomena • Electromagnetic radiation has both helpful and harmful implications for humans; the only part of this spectrum we can see is visible light • White light consists of a continuous spectrum of colors (ROY G BIV); this spectrum can be refracted, reflected, transmitted or absorbed by different materials, producing a variety of optical effects	• Why can adults typically not hear the ‘mosquito ringtone’? • What mechanisms do instruments use to enrich and amplify sound? • How are waves used to transfer energy and send and store information? • Why has digital technology replaced analog technology? • Why does UV radiation cause cancer, but microwave radiation is safe to use on food?

Science & Engineering Practices

Using Mathematics and Computational Thinking

- Use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations. (HS-PS4-1)

Engaging in Argument from Evidence

- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. (HS-PS4-3)

Obtaining, Evaluating, and Communicating Information

- Evaluate the validity and reliability of multiple claims that appear in scientific and technical texts or media reports, verifying the data when possible. (HS-PS4-4)
- Communicate technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and

Disciplinary Core Ideas

PS4.A: Wave Properties

- The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. (HS-PS4-1)
- Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. (Boundary: The discussion at this grade level is qualitative only; it can be based on the fact that two different sounds can pass a location in different directions without getting mixed up.) (HS-PS4-3)
- Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. (HS-PS4-5)
- Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. (HS-PS4-2)

PS4.B: Electromagnetic Radiation

- Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. (HS-PS4-3)
- When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, Xrays, gamma rays) can ionize atoms and cause damage to

Cross-Cutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS4-1)
- Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. (HS-PS4-4)
- Systems can be designed to cause a desired effect. (HS-PS4-5)

Systems and System Models

- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-PS4-3)

Stability and Change

- Systems can be designed for greater or lesser stability. (HS-PS4-2)

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D).

mathematically). (HS-PS4-5) Asking Questions and Defining Problems ● Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1) • Evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design. (HS-PS4-2) Constructing Explanations and Designing Solutions ● Evaluate a solution to a complex real world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	living cells. (HS-PS4-4) ● Photoelectric materials emit electrons when they absorb light of a high-enough frequency. (HS-PS45) PS3.D: Energy in Chemical Processes ● Solar cells are human-made devices that likewise capture the sun's energy and produce electrical energy. (secondary to HS-PS4-5) PS4.C: Information Technologies and Instrumentation ● Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. (HS-PS4-5) ETS1.A: Defining and Delimiting Engineering Problems ● Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1) ● Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) ETS1.B: Developing Possible Solutions ● When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and	(HS-PS4-5) Influence of Engineering, Technology, and Science on Society and the Natural World ● Modern civilization depends on major technological systems. (HS-PS4-5, HS-PS4-2) ● New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-3) ● Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HSPS4-2) Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena ● A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment. The science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally

	environmental impacts. (HS-ETS1-3)	modified in light of this new evidence. (HS-PS4-3)

Stage 2 – Assessment Evidence

Performance Task(s) May Include:	Other Evidence:
• Wave on a string or slinky: Students will create and observe a wave on a string or slinky. Their experimental design will adjust for the amplitude and frequency to demonstrate and analyze wave interactions and properties. (Possible Honors extension includes adjusting for damping and tension to observe additional properties) • Pulse rate: students will develop a conceptual and mathematical understanding of the concept of frequency by measuring pulse rates • Ripple Tank: Students will investigate wave properties (speed in a medium, reflection, diffraction, interference) using the PhET virtual ripple tank. • Resonance Tube: Velocity of Sound. Students will observe the resonance phenomenon in an open ended cylindrical tube, and use the resonance to determine the velocity of sound in air at ordinary temperatures. Rubric will be modified and activity scaffolded for conceptual versus honors students. • Sound Waves: Students will manipulate frequency to hear and explain how different sounds are modeled, described, and produced. • Doppler Effect: Students will explore the emission of sound waves from a moving source (both towards and away from an observer) and the change in frequency and perceived pitch of the wave via the Doppler effect. • Optics demos: students will carousel through a variety of optics demos and utilize their observations (both qualitative and quantitative) to construct meaning behind various visual phenomena, such as: polarization, reflection, refraction, color addition, color subtraction, etc. • Refraction through Glass: Students will trace the course of different rays of light through a rectangular glass slab at different angles of incidence, measure the angle of incidence, refraction. Honors students will have the extension of measuring the lateral displacement to verify Snell's law. • Introduction to the Electromagnetic Spectrum: NASA background resource • Technology for Imaging the Universe: NASA background resource • NASA LAUNCHPAD: Making Waves: NASA e-Clips activity on the electromagnetic spectrum	• Daily “clicker” formative assessment to gauge student understanding of concepts - teacher will adjust subsequent lessons as needed, based on this data. Students will be able to collaborate in groups and respond individually via their devices • Group based lab & Peer Oriented Guided Inquiry Learning (POGIL) approach: • Whole class discussion & teacher check-ins during collaborative group learning • Individual assessment at end of unit • In addition to any aforementioned differentiation at the Honors level, honors students will be expected to analyze more primary sources, will be assessed in align with higher standards set forth in rubrics, will be assessed on more complex mathematical and conceptual applications, and will engage in more self-directed exploration and learning.

● Radio Waves and Electromagnetic Fields: Phet simulation demonstrating wave generation, propagation and detection with antennas. ● Refraction: https://phet.colorado.edu/en/simulation/wave-interference - PHeT simulation addressing refraction of light at an interface. ● Wave Interference: Phet simulation of both mechanical and optical wave phenomena	

Stage 3 – Learning Plan

Learning Activities:
Please see activities & assessments mentioned above.   Daily class activities will include some sort of hook / phenomena / activating event to begin the lesson, followed by a whole class engagement activity. The majority of the learning experiences in the unit will be student designed so as to expose students to the framework of NGSS. Students will have opportunities to engage in the engineering design loop, create and answer questions, make predictions, collect and analyze data, and construct evidence based claims. Students will also have guided practice in proper measurement / unit conversion techniques, as well as data analysis, with opportunities to demonstrate their learning through lab investigations. Differentiation and scaffolding as needed for learners not meeting, or exceeding, performance expectations.

In this unit, students will explore a variety of phenomena that govern what they see and hear in everyday life. The Performance Expectations will align with these phenomena, along with an emphasis on how technologies work, with the driving question of “How are waves used to transfer energy and send and store information?” The disciplinary core idea in PS4 is broken down into Wave Properties, Electromagnetic Radiation, and Information Technologies and Instrumentation. Students should investigate wave properties so that they are able to identify and describe properties of waves both conceptually and mathematically, such as crests, troughs, wave speed, frequency, period, amplitude, and wavelength. Students will begin by studying mechanical waves (i.e., sound) through modeling with slinkies and sound demos guided by the teacher. Students will participate in activities to foster their understanding of the inversely proportional relationship between period and frequency, and use this to predict the frequency hearing range of an average human. Students will assess their own hearing frequency range and discuss whether their hearing has been damaged and if so, what habits or activities may have caused that. Students will extend their learning of wave concepts to model and observe wave interference.

The unit will conclude with a study of electromagnetic radiation (i.e., light). Students will complete their investigation through POGIL activities and demonstrations to model phenomena, such as reflection, refraction, color addition, color subtraction, etc. Students will be provided opportunities to compare and contrast ionizing (high frequency) and non-ionizing (low frequency) forms of radiation, and discuss the positive and negative applications of both types. Typically, different forms of electromagnetic radiation also have different abilities to penetrate matter. When matter absorbs non-ionizing radiation, the EM radiation is usually converted to thermal energy (heat). Ionizing radiation has the potential to damage to living cells, but in controlled scenarios, can have beneficial applications. Students should explore these cause-and-effect relationships through an investigation of scientific text. They should cite evidence from multiple sources; evaluate hypotheses, data, analysis, and conclusions; and assess strengths and limitations. Students can then explore color addition and subtraction phenomena by overlapping different spot lights and light filters, and should be able to predict what colors they will see when different light frequencies and/or pigments are combined.

These applications will be further developed with an emphasis on technologies, as well as data storage and transmission. Students should analyze modern technologies that rely on waves with respect to efficiency, cost, safety, environmental concerns, societal impact, etc.

Students who understand the concepts are able to:

- Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
- Use algebraic relationships to quantitatively describe relationships among the frequency, wavelength, and speed of waves traveling in various media.
- Use models (e.g., physical, mathematical, computer models) to simulate electromagnetic radiation systems and interactions—including energy, matter,and information flows—within and between systems at different scales.
- Communicate qualitative technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.
- Communicate technical information or ideas about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy in multiple formats (including orally, graphically, textually, and mathematically).
- Analyze technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy by specifying criteria and constraints for successful solutions.
- Evaluate a solution offered by technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy based on scientific knowledge,student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Technology and the Nature of Science:
Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D). (HS-PS4-5)

Influence of Engineering, Technology, and Science on Society and the Natural World

- Modern civilization depends on major technological systems. (HS-PS4-2),(HS-PS4-5)
- Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-PS4-2)

Possible Preconceptions/Misconceptions:

- When a wave travels through a medium, the medium moves with the wave
- Sound and light travel at similar speeds
- Light does not take time to travel
- Sound can travel through space
- Radio waves are sound waves

How do I reinforce or build literacy or mathematics skills?
The CCSS in Mathematics are demonstrated are generally demonstrated through unit conversions and algebraic manipulation of formulas in the activities described above. The CCSS in ELA is demonstrated when students are encouraged to read, write, analyze, and peer review throughout many formative assessments, such as: Laboratory Reports, Claims, Evidence, and Reasoning (CER), portfolios, reflections, and descriptions.

ELA:

- Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
- Assess the extent to which the reasoning and evidence in a text supports the author’s claim that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.
- Cite specific textual evidence to support the wave model or particle model in describing electromagnetic radiation, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text relating that electromagnetic radiation can be described either by a wave model or a particle model and that for some situations one model is more useful than the other, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
- Assess the extent to which the reasoning and evidence in a text describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter support the author’s claim or recommendation.
- Cite textual evidence to support analysis of science and technical texts describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., qualitative data, video multimedia) in order to address the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
- Gather relevant information from multiple authoritative print and digital sources describing the effects

that different frequencies of electromagnetic radiation have when absorbed by matter, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

- Write informative/explanatory texts about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy, including the narration of scientific procedures, experiments, or technical processes.
- Integrate and evaluate multiple sources of information about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy, presented in diverse formats and media (e.g., quantitative data, video, multimedia), in order to address a question or solve a problem.
- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text describing technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
- Synthesize information about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy from a range of sources. (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
- Assess the extent to which the reasoning and evidence in a text support the advantages of using digital transmission and storage of information.
- Cite specific textual evidence to support the advantages of using digital transmission and storage of information, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Evaluate advantages of using digital transmission and storage of information in text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

Mathematics:

- Represent symbolically relationships among the frequency, wavelength, and speed of waves traveling in various media, and manipulate the representing symbols. Make sense of quantities and relationships among the frequency, wavelength, and speed of waves traveling in various media.
- Use a mathematical model to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. Identify important quantities representing the frequency, wavelength, and speed of waves traveling in various media and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Interpret expressions that represent the frequency, wavelength, and speed of waves traveling in various media in terms of their context.
- Choose and produce an equivalent form of an expression to reveal and explain properties of the frequency, wavelength, and speed of waves traveling in various media.
- Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations when representing the frequency, wavelength, and speed of waves traveling in various media.