

Pascack Valley Regional High School District

**Pascack Hills High School, Montvale, New Jersey
Pascack Valley High School, Hillsdale, New Jersey**

Course Name: Applied Physics & Engineering

Born On: August, 2026
Board Approval: 8/24/26

New Jersey Curricular Mandates for Science Instruction

Disabled & LGBT:

18A:35-4.35 - History of disabled and LGBT persons included in middle and high school curriculum. A board of education shall include instruction on the political, economic, and social contributions of persons with disabilities and lesbian, gay, bisexual, and transgender people, in an appropriate place in the curriculum of middle school and high school students as part of the district's implementation of the New Jersey Student Learning Standards.

Diversity, Equity, and Inclusion (DEI):

C.18A:35-4.36a - Curriculum to include instruction on diversity and inclusion. 1. a. Beginning in the 2021-2022 school year, each school district shall incorporate instruction on diversity and inclusion in an appropriate place in the curriculum of students in grades kindergarten through 12 as part of the district's implementation of the New Jersey Student Learning Standards. b. The instruction shall: (1) highlight and promote diversity, including economic diversity, equity, inclusion, tolerance, and belonging in connection with gender and sexual orientation, race and ethnicity, disabilities, and religious tolerance; (2) examine the impact that unconscious bias and economic disparities have at both an individual level and on society as a whole; and (3) encourage safe, welcoming, and inclusive environments for all students regardless of race or ethnicity, sexual and gender identities, mental and physical disabilities, and religious beliefs. c. The Commissioner of Education shall provide school districts with sample learning activities and resources designed to promote diversity and inclusion.

Amistad Law:

N.J.S.A. 18A 52:16A-88 Every board of education shall incorporate the information regarding the contributions of African Americans to our country in an appropriate place in the curriculum of elementary and secondary school students.

Climate Change:

2026 NJSLS-Science: Earth's climate is now changing faster than at any point in the history of modern civilization, primarily as a result of human activities. Global climate change has already resulted in a wide range of impacts across New Jersey and in many sectors of its economy. The addition of academic standards that focus on climate change is important so that all students will have a basic understanding of the climate system, including the natural and human-caused factors that affect it. The underpinnings of climate change span across physical, life, as well as Earth and space sciences. The goal is for students to understand climate science as a way to inform decisions that improve quality of life for themselves, their community, and globally and to know how engineering solutions can allow us to mitigate impacts, adapt practices, and build resilient systems.

Dissection Law

N.J.S.A. 18A:35-4.25 and N.J.S.A. 18A:35-4.24 authorizes parents or guardians to assert the right of their children to refuse to dissect, vivisect, incubate, capture or otherwise harm or destroy animals or any parts thereof as part of a course of instruction.

Applied Physics & Engineering		
Unit Title	Approx # of weeks	Months
<i>Benchmark #1</i>		
Introduction to Engineering Design and Technology	4 Weeks	August – September
Motion in Action – Designing with Newton’s Laws	6 weeks	October - November
Forces in Balance: Statics, Equilibrium, and Structural Engineering	8 weeks	November - January
<i>Benchmark #2</i>		
Machines in Motion – Torque, Rotation & Mechanical Systems	7 weeks	January - March
Engineering Earth and Space: Energy, Systems, and Technology	6 weeks	March - April
Engineering the Future – Bridge Design Capstone	9 weeks	April - June
<i>Benchmark #3</i>		

Applied Physics and Engineering			
Unit 1: Introduction to Engineering Design & Technology			
Anchoring Phenomena: Communities often need to cross rivers, valleys, highways, or railroads. While two bridges may span the same distance, they often look dramatically different and vary greatly in cost, safety, durability, environmental impact, and aesthetics. Driving Question: How do engineers use science, mathematics, and the engineering design process to create safe, efficient, and innovative solutions to real-world problems? Related Phenomena - Local bridge designs (George Washington Bridge, Bayonne Bridge, Mario Cuomo Bridge, Garden State Parkway bridges) - Pedestrian bridges versus highway bridges - Structural failures and redesigns - Everyday engineered products (chairs, bicycles, smartphones) 3D printed prototypes - CAD models used by engineers			
Pacing: 4-5 Weeks			
New Jersey Student Learning Standards (NJSLS)			
Essential Questions	Student Learning Objectives	Suggested Tasks/Activities	Evidence of Learning (Assessment)
- What distinguishes science from engineering? - How does the engineering design process help solve complex problems? - Why must engineers consider criteria, constraints, and trade-offs before developing solutions? - How do models and prototypes improve engineering designs? - What makes an effective engineering team? - How does organization contribute to successful engineering projects? - What responsibilities do engineers have to society and the environment?	Student will be able to: - Differentiate between science, technology, and engineering. - Explain each stage of the engineering design process. - Identify criteria and constraints within an engineering problem. - Analyze available resources and recognize limitations during the design process. - Conduct research using reliable technical sources. - Generate multiple possible design solutions. - Communicate design ideas through sketches, diagrams, CAD models, and written documentation.	- Investigate a variety of bridge designs and identify how engineers balance criteria, constraints, and trade-offs when solving real-world problems. - Compare the roles of science, technology, and engineering by analyzing real-world examples and discussing how each contributes to solving societal problems. - Participate in a team-based engineering design challenge (e.g., paper tower or index card bridge) that requires planning, prototyping, testing, redesign, and reflection. - Develop and maintain an engineering notebook to document research, brainstorming, design sketches, data collection, testing results, reflections, and iterative improvements throughout the course.	Formative Assessments - Engineering notebook entries documenting the engineering design process - CAD sketches, technical drawings, and digital design models - Exit tickets and engineering design reflections - Class discussions and collaborative design critiques - Teacher observation of workshop safety procedures and tool use - Prototype design reviews and progress conferences - Design proposal presentations - Peer feedback and iterative

	● Maintain an organized engineering notebook. ● Demonstrate safe use of laboratory equipment and fabrication tools. ● Collaborate effectively during engineering investigations. ● Reflect on failures and redesign solutions using evidence collected during testing.	● Apply the Engineering Design Process to define a problem, identify criteria and constraints, conduct research, generate multiple design solutions, evaluate alternatives, construct prototypes, test designs, analyze results, and communicate findings. ● Investigate the seven resources of technology (time, people, materials, energy, information, capital, and tools/equipment) and evaluate how resource limitations influence engineering decisions. ● Research historical and contemporary engineering innovations to determine how technological solutions have positively and negatively impacted society and the environment. ● Create hand-drawn technical sketches and introductory CAD models using engineering design software to communicate proposed solutions. ● Analyze examples of successful and unsuccessful engineering designs to identify characteristics of effective problem solving and iterative improvement. ● Collaborate in design teams to develop, communicate, evaluate, and revise engineering solutions using evidence collected during prototype testing. ● Complete laboratory and fabrication safety training, demonstrate proper use of personal protective equipment (PPE), and safely operate classroom tools and equipment.	design reflections ● Vocabulary quizzes on engineering terminology and design concepts ● Shop safety assessment and equipment proficiency check <u>Performance Assessments</u> ● Completion of the Engineering Design Process Portfolio ● CAD model development and technical documentation ● Prototype fabrication using makerspace equipment ● Prototype testing and data collection ● Engineering notebook documenting iterative design improvements ● Engineering presentation explaining design decisions and supporting scientific principles <u>Summative Assessment</u> Engineering Design Fundamentals Challenge Students will design, model, fabricate, test, and refine a functional product that addresses an authentic engineering problem while satisfying specified design criteria and constraints. Students will: ● Research an engineering problem and identify
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Interdisciplinary Connections	<u>ELA</u> RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. RST.11-12.2 Determine the central ideas or conclusions of a science or technical text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. WHST.11-12.7 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.11-12.9 Draw evidence from informational texts to support analysis, reflection, and research. SL.11-12.4 Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task.		
Career Readiness, Life Literacies, and Key Skills	9.4A.1 Apply critical thinking and problem-solving strategies during structured learning experiences. 9.4A.2 Demonstrate creativity and innovation in generating ideas, products, and solutions to authentic problems. 9.4C.1 Demonstrate effective interpersonal communication skills in an active listening and respectful discussion environment. 9.4C.2 Collaborate effectively with individuals of diverse perspectives to accomplish common goals. 9.4D.1 Demonstrate responsible decision-making when identifying and solving problems.		
Computer Science and Design Thinking	8.1.12.IC.1 Evaluate the ways computing impacts personal, ethical, social, economic, and cultural practices. 8.2.12.ED.2 Apply the design process to create innovative solutions that address real-world problems by identifying criteria, constraints, trade-offs, and potential impacts. 8.2.12.ITH.2 Propose an innovative solution to a real-world problem using appropriate technologies and engineering design practices. 8.2.12.NT.1 Research and evaluate existing and emerging technologies to determine their impact on society, the environment, and the global economy.		
Modifications			
Multi-Lingual Learners	Students with Special Needs/504s	At-Risk	Gifted and Talented
- Pre-teach engineering and scientific vocabulary using visuals, diagrams, and bilingual resources when appropriate. - Provide sentence frames, graphic organizers, and structured collaborative activities to support academic discussions.	- Provide graphic organizers, engineering design templates, and guided notes to support the engineering design process. - Break complex design challenges into smaller, manageable tasks with	- Scaffold engineering design challenges through teacher-guided checkpoints and frequent formative feedback. - Provide partially completed data tables, design organizers, and calculation templates. - Reinforce measurement, graphing,	- Extend engineering challenges by incorporating additional design constraints such as cost, sustainability, efficiency, or material limitations. - Encourage independent research on emerging

● Pair students with supportive peers during engineering design challenges and laboratory investigations. ● Allow multiple methods of demonstrating understanding, including labeled diagrams, models, demonstrations, and oral explanations. ● Utilize translated directions and digital translation tools as appropriate.	frequent teacher check-ins. ● Provide extended time for engineering design, prototype construction, testing, and written reflections as outlined in student IEPs. ● Utilize visual demonstrations, physical models, and teacher modeling to reinforce engineering concepts. ● Allow alternative methods for demonstrating understanding, including oral presentations, digital portfolios, videos, or illustrated design notebooks. ● Provide adaptive tools and materials to support safe participation in laboratory investigations and construction activities.	and problem-solving skills through guided practice before independent application. ● Utilize small-group instruction to review prerequisite physics and engineering concepts. ● Allow opportunities for revision and redesign following teacher feedback.	engineering technologies and real-world design applications. ● Require advanced analysis of prototype performance using quantitative data and technical justifications. ● Provide opportunities to utilize computer modeling, CAD software, or simulation tools to optimize designs. ● Encourage leadership roles during collaborative engineering projects and peer mentoring.
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Applied Physics and Engineering		
Unit 2: Motion in Action - Designing with Newton's Laws		
Anchoring Phenomena: Why do some vehicles protect passengers during a collision while others experience catastrophic failure? Students investigate how Newton's Laws govern vehicle motion, momentum transfer, and collision forces. They analyze how engineers use physics to design safer automobiles through crumple zones, airbags, seatbelts, and impact-absorbing materials. Throughout the unit, students apply force analysis and Newton's Laws to explain how engineering design reduces injury during collisions. Related Phenomenon: Why do airbags and seatbelts reduce injuries during automobile collisions? Why do modern vehicles include crumple zones while older vehicles did not? Why does a loaded shopping cart require more force to accelerate than an empty one? Why does a football player continue moving after being tackled? Why do passengers lurch forward when a vehicle stops suddenly? How do engineers design helmets to reduce impact forces in sports and construction? Why do race cars and Formula One vehicles use lightweight composite materials? Why is stopping distance greater at higher speeds? How do friction and surface conditions affect vehicle braking? Why are guardrails, crash barriers, and highway safety systems designed to deform during impacts?		
Pacing: 6 Weeks		
New Jersey Student Learning Standards (NJSLS)		
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. 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-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.		
Science & Engineering Practices	Disciplinary Core Ideas	Cross-Cutting Concepts
Asking Questions and Defining Problems - Ask questions to clarify relationships among forces, motion, momentum, and collisions. - Define engineering problems by identifying design criteria, constraints,	PS2.A: Forces and Motion - Newton's Second Law accurately predicts changes in the motion of macroscopic objects. - The motion of an object is determined by the net force acting on it and its mass.	Patterns Patterns in motion, force, and momentum data can be identified and used to predict the behavior and performance of engineered systems. Cause and Effect

and performance requirements for devices that control or minimize impact forces. Developing and Using Models - Develop and use free-body diagrams, mathematical models, CAD models, and physical prototypes to explain and predict motion. - Use computational and physical models to evaluate engineering solutions. Planning and Carrying Out Investigations - Design and conduct investigations to measure force, acceleration, velocity, momentum, and collision outcomes. - Plan controlled tests to evaluate the performance of engineered prototypes. Analyzing and Interpreting Data - Analyze quantitative data collected during laboratory investigations and engineering testing. - Interpret motion graphs, force measurements, and collision data to evaluate engineering performance and identify opportunities for improvement. Using Mathematics and Computational Thinking - Apply mathematical relationships to calculate force, acceleration, momentum, impulse, and velocity. - Analyze experimental data using graphs, equations, spreadsheets, and digital analysis tools to support engineering decisions. Constructing Explanations and Designing Solutions	- Free-body diagrams and mathematical models can be used to analyze and predict motion. PS2.B: Types of Interactions - Forces occur between interacting objects and always occur in equal and opposite pairs. - Momentum is conserved within a closed system when there is no net external force. - Collision forces can be reduced through engineering design by increasing the time over which momentum changes. - The molecular structure and properties of materials influence their performance in engineered systems subjected to forces and impacts. ETS1.A: Defining and Delimiting Engineering Problems - Successful engineering solutions are developed by identifying criteria, constraints, and performance expectations. - Engineering problems often involve competing constraints including safety, cost, materials, manufacturability, and performance. ETS1.B: Developing Possible Solutions - Engineers evaluate multiple possible solutions through modeling, prototyping, testing, and analysis. - Design decisions are supported by scientific principles, mathematical analysis, and empirical evidence. ETS1.C: Optimizing the Design Solution - Engineering design is an iterative process in which testing, data collection, and redesign improve performance. - Optimization requires evaluating trade-offs among competing design criteria and constraints while maximizing overall effectiveness.	- Cause-and-effect relationships explain how forces influence motion and how engineering design decisions affect the performance of moving systems. - Empirical evidence is used to identify relationships between design variables and engineering outcomes. Scale, Proportion, and Quantity - Quantitative relationships among force, mass, acceleration, momentum, and impulse are essential for analyzing and designing engineering solutions. - Appropriate measurement, precision, and scale are necessary to accurately evaluate prototype performance. Systems and System Models - Engineered systems consist of interacting components whose behavior can be modeled, analyzed, tested, and optimized. - Physical, mathematical, and computational models are used to predict system behavior and evaluate design performance. Structure and Function - The design, geometry, and material properties of engineered objects determine their function, durability, and ability to withstand forces and collisions. - Engineers select materials and structural features based on desired performance characteristics. Stability and Change
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- Construct scientific explanations that describe how Newton's Laws govern motion and interactions. - Design, fabricate, test, and refine engineering solutions that minimize collision forces while satisfying established design criteria and constraints. Engaging in Argument from Evidence - Defend engineering design decisions using quantitative data, experimental evidence, and scientific reasoning. - Evaluate competing engineering solutions based on performance, safety, efficiency, and design constraints. Obtaining, Evaluating, and Communicating Information - Obtain and evaluate scientific and technical information related to transportation safety, collision engineering, and material selection. - Communicate engineering solutions through technical presentations, engineering notebooks, CAD drawings, and prototype demonstrations.		- Changes in forces acting on a system result in changes in motion and system behavior. - Engineering solutions are improved through iterative testing, data analysis, and redesign to enhance stability, safety, and overall performance.
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Essential Questions	Student Learning Objectives	Suggested Tasks/Activities	Evidence of Learning (Assessment)
- How do engineers use Newton's Laws to design products that move safely, efficiently, and predictably? - How do forces influence the motion and performance of engineered systems? - How can mathematical models be used to predict the behavior of	Student will be able to: - Analyze balanced and unbalanced forces using vector diagrams and free-body diagrams. - Apply Newton's First, Second, and Third Laws to explain and predict the motion of objects.	Engineering Investigation - Analyze real-world examples of vehicle collisions and engineering safety systems to identify how Newton's Laws influence design. - Investigate motion using motion sensors, photogates, and video analysis software.	Formative Assessments - Engineering notebook entries documenting force analyses, free-body diagrams, design sketches, and testing results - Exit tickets focused on Newton's Laws and

moving objects? - How do engineers balance performance, safety, cost, and material selection when designing products subjected to forces and collisions? - How can data collected during testing be used to improve engineering designs? - How do momentum and collision forces influence the design of modern transportation and safety systems? - How does the engineering design process transform scientific principles into functional technologies? - How can digital fabrication tools be used to prototype, test, and refine engineering solutions?	- Calculate net force, acceleration, momentum, and impulse using appropriate mathematical models. - Analyze motion using graphical, mathematical, and experimental data. - Design and conduct investigations to collect quantitative data related to force and motion. - Apply the engineering design process to develop solutions to problems involving motion, collisions, and force interactions. - Create engineering sketches and CAD models that incorporate principles of force and motion. - Safely fabricate prototypes using makerspace equipment, including 3D printers, laser cutters, and appropriate workshop tools. - Evaluate prototype performance through experimental testing and quantitative data analysis. - Modify and optimize engineering designs based on evidence collected during testing. - Communicate engineering design decisions using appropriate scientific principles, technical vocabulary, and supporting evidence.	- Conduct inquiry-based laboratory investigations exploring balanced and unbalanced forces, inertia, acceleration, friction, momentum, and impulse. - Develop and interpret free-body diagrams for a variety of engineering systems. Physics Applications - Solve engineering problems involving Newton's First, Second, and Third Laws using mathematical models. - Analyze motion through position-time, velocity-time, and acceleration-time graphs. - Investigate the effects of mass, force, friction, and surface conditions on acceleration. - Model momentum conservation and collision forces using laboratory investigations and computer simulations. Engineering Design Challenge - Design a collision safety device or prototype vehicle that minimizes impact forces while meeting established engineering constraints. - Research existing engineering solutions including airbags, crumple zones, roll cages, safety harnesses, and impact-absorbing materials. - Develop engineering sketches and technical drawings that communicate proposed design solutions. - Create digital CAD models using Onshape, Fusion 360, SolidWorks, or comparable software. Digital Fabrication - Safely operate makerspace	engineering applications - Motion graph interpretation and problem-solving exercises - Free-body diagram practice and peer review - CAD sketches and prototype design conferences - Teacher observation of laboratory investigations and workshop participation - Prototype design critiques and engineering design reviews - Small-group discussions analyzing engineering failures and successes - Data analysis from motion, force, and collision investigations - Vocabulary quizzes on force, motion, momentum, and engineering terminology Performance Assessments - Laboratory investigation of Newton's Laws using motion sensors and force probes - Motion graph and free-body diagram analysis - Engineering design proposal including design criteria, constraints, and technical sketches - CAD model development and technical
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	Collaborate effectively to design, fabricate, test, and refine engineering solutions that satisfy established design criteria and constraints.	equipment including 3D printers, laser cutters, and appropriate workshop tools to fabricate prototype components. - Select appropriate construction materials based on engineering requirements, strength, durability, cost, and manufacturability. - Assemble and refine engineered prototypes using accepted fabrication and safety practices. Testing and Optimization - Conduct controlled testing of engineered prototypes using quantitative measurements. - Collect, organize, and analyze experimental data related to motion, force, acceleration, and collisions. - Evaluate prototype performance against established design criteria and engineering constraints. - Modify and optimize designs through iterative testing and redesign. Communication and Reflection - Maintain an engineering design notebook documenting research, design decisions, testing data, design revisions, and reflections. - Present engineering solutions using scientific evidence, mathematical analysis, and technical vocabulary. - Defend design decisions through collaborative engineering critiques and peer review. - Reflect on how Newton's Laws informed the design, testing, and optimization of the final engineering solution.	documentation - Prototype fabrication using makerspace equipment - Prototype testing, quantitative data collection, and engineering analysis - Engineering notebook documenting iterative design improvements - Engineering presentation explaining how Newton's Laws influenced design decisions Summative Assessment Collision Safety Engineering Challenge Students will design, fabricate, and optimize a prototype vehicle or collision safety device that minimizes impact forces while satisfying established engineering criteria and constraints related to size, materials, cost, safety, and performance. Students will: - Research real-world transportation safety systems and collision engineering. - Apply Newton's Laws, momentum, and impulse to develop an engineering solution. - Create engineering sketches and CAD models. - Fabricate a working prototype using 3D
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			printers, laser cutters, and appropriate workshop tools. ● Conduct controlled collision testing and collect quantitative performance data. ● Analyze test results using mathematical models and scientific evidence. ● Modify and optimize the design through multiple iterations. ● Present and defend engineering decisions using physics principles, engineering evidence, and technical communication. <u>Final Deliverables</u> ● Engineering Design Notebook ● Research Summary ● CAD Model and Technical Drawings ● Fabricated Prototype ● Collision Testing Data and Analysis ● Design Iteration Documentation ● Final Engineering Presentation ● Engineering Reflection and Self-Assessment
Interdisciplinary Connections	<u>ELA</u> RI.CR.11–12.1 Cite strong and thorough textual evidence to support analysis of scientific and technical texts. RI.CI.11–12.2 Determine and analyze central ideas of complex informational and technical texts. W.AW.11–12.1 Write arguments to support claims using valid reasoning and relevant evidence. W.WR.11–12.5 Conduct short and sustained research projects to answer engineering design questions. SL.PE.11–12.1 Initiate and participate effectively in collaborative discussions.		

	SL.PI.11–12.4 Present information, findings, and supporting evidence clearly and logically. Mathematics F.IF.B.4 Interpret functions that arise in applications in terms of the context. F.IF.C.7 Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases. F.IF.C.9 Compare properties of two functions, each represented in a different way (algebraically, graphically, numerically in tables, or by verbal descriptions). N.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. N.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. N.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. S.ID.B.6 Represent data on two quantitative variables on a scatter plot, and describe how the variables are related: Social Studies 6.1.12.EconET.8.a Analyze the role of technological innovation in increasing economic productivity and improving quality of life.		
Career Readiness, Life Literacies, and Key Skills	9.4.12.CT.1 Identify problems, collect data, analyze information, and use critical thinking to develop and evaluate solutions. 9.4.12.CT.2 Explain how individuals and teams apply critical thinking and collaborative problem-solving skills to develop engineering solutions. 9.4.12.IML.5 Evaluate information from multiple sources to support design decisions and communicate engineering findings. 9.4.12.TL.2 Generate innovative solutions by applying technology and engineering design processes.		
Computer Science and Design Thinking	8.2.12.ED.1 Analyze a design challenge and develop criteria and constraints for an engineering solution. 8.2.12.ED.2 Evaluate potential solutions using data, testing, and engineering analysis. 8.2.12.ED.3 Apply an iterative design process to prototype, test, and refine engineering solutions. 8.2.12.ED.5 Evaluate the effectiveness of engineering solutions based on design criteria and constraints.		
Modifications			
Multi-Lingual Learners	Students with Special Needs/504s	At-Risk	Gifted and Talented
● Pre-teach vocabulary related to force, motion, momentum, collisions, engineering design, and fabrication using visuals, demonstrations, and bilingual resources. ● Provide illustrated engineering design guides, CAD tutorials, and	● Provide graphic organizers, guided notes, calculation templates, and engineering design organizers. ● Break complex engineering challenges into manageable design milestones with regular teacher check-ins.	● Scaffold force and motion concepts using guided inquiry, teacher modeling, and frequent formative assessment. ● Reinforce prerequisite mathematics skills, including graph interpretation, measurement, unit conversions, and formula application.	● Extend engineering challenges by incorporating advanced design constraints such as cost analysis, material optimization, sustainability, manufacturability, and efficiency.

labeled diagrams to support concept development. ● Use sentence frames and structured academic discussions to support scientific and engineering communication. ● Pair students strategically during laboratory investigations, engineering design challenges, and fabrication activities. ● Allow students to demonstrate understanding through diagrams, CAD models, prototypes, oral presentations, and engineering demonstrations in addition to written responses. ● Provide translated directions and digital translation tools when appropriate.	● Provide extended time for calculations, laboratory investigations, CAD development, fabrication, and prototype testing as specified by student plans. ● Utilize teacher modeling, physical demonstrations, simulations, and visual supports to reinforce Newton's Laws and engineering concepts. ● Provide adaptive tools, modified equipment, or alternative fabrication methods as needed to ensure safe participation in makerspace activities. ● Allow multiple methods of demonstrating mastery including oral explanations, digital presentations, engineering notebooks, CAD models, or fabricated prototypes. ● Implement accommodations specified in student IEPs and 504 plans, including assistive technology, preferential seating, organizational supports, and flexible assessment formats.	● Provide partially completed engineering notebooks, calculation guides, and CAD templates when appropriate. ● Utilize small-group instruction during physics investigations, engineering design, and fabrication activities. ● Provide structured checkpoints throughout the engineering design process to promote organization and project completion. ● Encourage collaborative learning through defined engineering team roles and peer mentoring. ● Provide opportunities for prototype revision and reassessment based on teacher feedback.	● Encourage students to develop multiple prototype iterations and evaluate design trade-offs using quantitative data. ● Utilize advanced CAD software features, computer simulations, and engineering analysis tools to optimize designs. ● Require independent research into automotive safety systems, impact engineering, biomechanics, and emerging engineering technologies. ● Challenge students to design experiments that investigate variables beyond the required laboratory activities. ● Encourage leadership roles during collaborative engineering projects and peer mentoring within fabrication teams. ● Provide opportunities to present engineering solutions to authentic audiences using professional engineering documentation and technical presentations.
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Applied Physics and Engineering		
Unit 3: Forces in Balance: Statics, Equilibrium, and Structural Engineering		
Anchoring Phenomena: How can a lightweight structure support a load many times greater than its own weight without collapsing?		
Related Phenomena: Why are triangles used so frequently in bridges, towers, cranes, and roof trusses? Why can two structures built from the same amount of material support dramatically different loads? Why do some structural members experience tension while others experience compression? Why do long, thin structural members buckle under compression? How does the location of a load affect where a structure fails? Why are I-beams shaped differently from solid rectangular beams? How do engineers determine where forces travel through a bridge or building? Why do engineers sometimes intentionally allow one component of a structure to fail before another? How can changing geometry increase structural strength without adding additional material? How do engineers balance strength, weight, cost, safety, and material use?		
Pacing: 8 Weeks		
New Jersey Student Learning Standards (NJSLS)		
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. HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. HS-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.		
Science & Engineering Practices	Disciplinary Core Ideas	Cross-Cutting Concepts
Asking Questions and Defining Problems - Define structural engineering problems by identifying quantitative and qualitative criteria, constraints, loads, materials, safety requirements, and performance expectations. - Ask questions about how geometry, material properties, connections, and	PS2.A: Forces and Motion - Newton's Second Law describes the mathematical relationship among net force, mass, and acceleration. - A static structure is in translational equilibrium when the forces acting on it are balanced. - Forces can be represented and analyzed using vectors, components, and free-body diagrams.	Patterns - Patterns in structural geometry, force distribution, deformation, and failure can be identified and used to predict structural performance. - Patterns observed during repeated load testing can inform engineering design and redesign decisions.

load placement affect structural stability and failure. Developing and Using Models - Develop and use free-body diagrams, vector models, truss diagrams, CAD models, and physical prototypes to represent structural systems. - Use models to predict force distribution, tension, compression, equilibrium, and potential structural failure. Planning and Carrying Out Investigations - Plan and conduct investigations of equilibrium, tension, compression, stress, strain, buckling, and structural performance. - Conduct controlled load tests to evaluate fabricated structural components and prototypes. Analyzing and Interpreting Data - Analyze load, deformation, material-testing, and structural-failure data to evaluate performance. - Compare predicted structural behavior with experimental results and identify sources of discrepancy. - Use testing data to identify weaknesses and opportunities for redesign. Using Mathematics and Computational Thinking - Apply vectors, force components, equilibrium equations, geometry, and trigonometry to analyze structural systems. - Use mathematical and computational models to calculate member forces,	- Applied loads and support reactions determine how forces are distributed through an engineered structure. PS2.B: Types of Interactions - Forces result from interactions between objects and structural components. - Structural members transmit forces through tension and compression. - Material properties influence how structural components respond to applied forces, deformation, and loading. - The molecular-level structure of designed materials contributes to their strength, stiffness, flexibility, and suitability for particular engineering applications. ETS1.A: Defining and Delimiting Engineering Problems - Engineering problems are defined through quantitative and qualitative criteria and constraints. - Structural designs must account for factors such as load capacity, safety, material limitations, cost, dimensions, weight, manufacturability, and intended function. - Complex structural problems can be broken into smaller problems involving individual members, joints, connections, supports, and load paths. ETS1.B: Developing Possible Solutions - Multiple structural solutions can be developed and compared using scientific principles, mathematical analysis, models, simulations, and testing. - Engineering drawings, CAD models, physical prototypes, and computational models can be used to predict and evaluate structural performance.	Cause and Effect - Changes in load magnitude, load location, geometry, material properties, or connections can cause changes in structural stability and performance. - Experimental evidence can be used to determine the causes of deformation, buckling, joint failure, and structural collapse. Scale, Proportion, and Quantity - Quantitative relationships among force, dimensions, mass, stress, strain, and load capacity are used to analyze structural systems. - Scale models and CAD representations can be used to investigate structural behavior while recognizing limitations when applying results to full-scale structures. - Strength-to-weight ratios provide a quantitative measure for comparing and optimizing structural designs. Systems and System Models - A structure is a system composed of interacting members, joints, supports, and loads. - Free-body diagrams, truss diagrams, CAD models, simulations, and physical prototypes can be used to represent and analyze structural systems. - Changes to one component of a structure can affect forces and performance throughout the entire system.
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reaction forces, load distribution, and strength-to-weight performance. - Use CAD and other digital tools to model, analyze, and optimize structural designs. Constructing Explanations and Designing Solutions - Construct evidence-based explanations for why structures remain stable, deform, buckle, or fail under applied loads. - Design, fabricate, test, and refine structural solutions that satisfy specified criteria and constraints. - Apply knowledge of force distribution, material properties, and structural geometry to improve engineering performance. Engaging in Argument from Evidence - Defend structural design and material-selection decisions using calculations, experimental data, and engineering evidence. - Evaluate competing structural solutions based on strength, stability, safety, material efficiency, cost, and manufacturability. - Use evidence from destructive testing and failure analysis to justify proposed design improvements. Obtaining, Evaluating, and Communicating Information - Obtain and evaluate scientific and technical information about structural systems, materials, construction methods, and engineering failures.	- Testing individual components can provide evidence that informs the design of larger structural systems. ETS1.C: Optimizing the Design Solution - Structural designs are optimized through iterative cycles of analysis, fabrication, testing, failure analysis, and redesign. - Testing data can be used to identify structural weaknesses and improve load distribution, geometry, connections, and material use. - Optimization requires evaluating trade-offs among competing criteria such as strength, weight, safety, cost, material efficiency, aesthetics, and manufacturability.	Structure and Function - The geometry, dimensions, arrangement, and material composition of structural components influence how they function under load. - Structural forms such as triangles, trusses, arches, columns, and bracing systems distribute forces in different ways. - Material properties and component geometry determine how effectively structural members resist tension, compression, deformation, and buckling. Stability and Change - Structures remain stable when forces are appropriately balanced and distributed. - Increasing loads or altering structural conditions can cause deformation, instability, or failure. - Engineers use testing, failure analysis, and iterative redesign to improve structural stability, safety, and performance.
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- Communicate structural designs through engineering notebooks, technical drawings, CAD models, calculations, data displays, physical prototypes, and technical presentations. - Present and defend final engineering solutions using physics principles, mathematical analysis, and experimental evidence.			
Essential Questions	Student Learning Objectives	Suggested Tasks/Activities	Evidence of Learning (Assessment)
- How do engineers use the principles of force and equilibrium to design stable structures? - How can forces be balanced and distributed throughout a structure? - How can free-body diagrams and mathematical models be used to predict whether a structure will remain in equilibrium? - How do tension and compression affect structural components differently? - How does geometry influence the strength, stability, and efficiency of a structure? - Why are triangles and trusses commonly used in structural engineering? - How do material properties affect the way structural components respond to applied loads? - How and why do structures fail under different loading conditions?	Student will be able to: - Identify and analyze forces acting on static structures. - Construct and interpret free-body diagrams representing applied forces, reaction forces, and loads. - Resolve forces into appropriate vector components. - Apply the conditions of static equilibrium to analyze engineered structures. - Calculate forces acting within structural systems using appropriate mathematical models. - Distinguish between tension and compression and identify structural members experiencing each type of force. - Analyze how forces are transferred through trusses and other structural systems.	- Identify and analyze forces acting on static structures. - Construct and interpret free-body diagrams representing applied forces, reaction forces, and loads. - Resolve forces into appropriate vector components. - Apply the conditions of static equilibrium to analyze engineered structures. - Calculate forces acting within structural systems using appropriate mathematical models. - Distinguish between tension and compression and identify structural members experiencing each type of force. - Analyze how forces are transferred through trusses and other structural systems. - Apply the method of joints to determine forces acting on individual truss members. - Explain how geometry influences structural strength, stability, and load	Formative Assessments - Engineering notebook entries documenting force analysis, calculations, design decisions, and structural observations - Free-body diagram checks - Vector resolution and static equilibrium problem sets - Exit tickets on tension, compression, equilibrium, stress, strain, and structural stability - Method of joints calculations and truss-analysis exercises - Force-table investigation data and analysis - Tension and compression laboratory analysis - Stress/strain and material-testing data analysis - Structural geometry mini-challenges

• How can engineers maximize strength while minimizing weight and material use? • How can CAD, digital fabrication, and physical prototyping be used to develop and evaluate structural solutions? • How can load-testing data be used to identify weaknesses and improve a structural design? • How do engineers balance strength, safety, cost, material use, aesthetics, and other constraints when designing structures? • How does iterative testing and redesign lead to safer and more efficient structures?	• Apply the method of joints to determine forces acting on individual truss members. • Explain how geometry influences structural strength, stability, and load distribution. • Investigate stress, strain, elasticity, buckling, and other modes of structural deformation or failure. • Compare materials based on properties such as strength, stiffness, weight, durability, and suitability for a particular engineering application. • Analyze experimental load-testing data to identify patterns, structural weaknesses, and likely points of failure. • Establish quantitative and qualitative criteria and constraints for a structural engineering problem. • Develop sketches, technical drawings, and CAD models of proposed structural solutions. • Apply physics principles and structural analysis to predict how a proposed design will respond to applied loads. • Safely use 3D printers, laser cutters, and appropriate workshop tools to fabricate structural components and prototypes. • Conduct controlled load tests to evaluate the performance	distribution. • Investigate stress, strain, elasticity, buckling, and other modes of structural deformation or failure. • Compare materials based on properties such as strength, stiffness, weight, durability, and suitability for a particular engineering application. • Analyze experimental load-testing data to identify patterns, structural weaknesses, and likely points of failure. • Establish quantitative and qualitative criteria and constraints for a structural engineering problem. • Develop sketches, technical drawings, and CAD models of proposed structural solutions. • Apply physics principles and structural analysis to predict how a proposed design will respond to applied loads. • Safely use 3D printers, laser cutters, and appropriate workshop tools to fabricate structural components and prototypes. • Conduct controlled load tests to evaluate the performance of fabricated structures. • Compare predicted structural performance with experimental results and explain discrepancies using evidence. • Evaluate engineering trade-offs involving strength, weight, material use, cost, safety, manufacturability, and aesthetics. • Use testing evidence to redesign and optimize structural solutions.	• CAD model progress checks and design conferences • Peer design critiques and structural design reviews • Teacher observation of safe and appropriate workshop/fabrication practices Performance Assessments • Static Equilibrium Investigation: Students predict forces mathematically, test the system experimentally, and compare theoretical and measured results. • Structural Member Testing: Students fabricate and test structural components under tension and/or compression and analyze failure modes. • Material Performance Investigation: Students compare materials using quantitative evidence related to strength, deformation, mass, and structural performance. • Truss Analysis: Students use free-body diagrams and the method of joints to determine forces within a structural system. • CAD Structural Design: Students create a digital structural model that satisfies established dimensional, material, and
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	of fabricated structures. • Compare predicted structural performance with experimental results and explain discrepancies using evidence. • Evaluate engineering trade-offs involving strength, weight, material use, cost, safety, manufacturability, and aesthetics. • Use testing evidence to redesign and optimize structural solutions. • Maintain an engineering notebook documenting calculations, design decisions, fabrication processes, testing data, failure analysis, and design iterations. • Communicate and defend a final structural design using physics principles, mathematical analysis, experimental evidence, and engineering reasoning.	• Maintain an engineering notebook documenting calculations, design decisions, fabrication processes, testing data, failure analysis, and design iterations. • Communicate and defend a final structural design using physics principles, mathematical analysis, experimental evidence, and engineering reasoning.	performance constraints. • Prototype Load Test: Students conduct controlled testing, collect quantitative load and deformation data, identify the mode and location of failure, and compare actual performance with predictions. • Engineering Design Notebook: Students document calculations, sketches, CAD development, fabrication procedures, testing data, failure analysis, and design iterations. Benchmark • Linkit! Form C Summative Assessment Structural Engineering Challenge Students will design, analyze, fabricate, test, and optimize a lightweight structural system capable of supporting the greatest possible load while satisfying specified engineering criteria and constraints. Students will: • Establish quantitative and qualitative design criteria and constraints. • Analyze anticipated loads and force distribution. • Identify members expected to experience tension and
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			compression. ● Develop engineering sketches and technical drawings. ● Create a CAD model of the proposed structure. ● Select materials based on structural properties and design requirements. ● Fabricate structural components using laser cutters, 3D printers, and/or appropriate workshop tools. ● Assemble a functional structural prototype. ● Predict maximum load capacity and likely mode/location of failure. ● Conduct controlled load testing and collect quantitative performance data. ● Calculate and compare strength-to-weight performance. ● Analyze structural failure using physics and engineering principles. ● Redesign or optimize the structure based on testing evidence. ● Present and defend the final engineering solution. Final Deliverables: Engineering Design Notebook; force and structural calculations; CAD model/technical drawings;
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			fabricated prototype; load-testing data; failure analysis; design iteration documentation; final engineering presentation; individual reflection.
Interdisciplinary Connections	ELA RI.CR.11–12.1 – Cite strong and thorough textual evidence when analyzing informational and technical sources. RI.CI.11–12.2 – Determine and analyze central ideas in complex informational and technical texts. W.AW.11–12.1 – Develop evidence-based arguments and claims. W.WR.11–12.5 – Conduct research to answer questions and solve problems. SL.PE.11–12.1 – Participate effectively in collaborative discussions. SL.PI.11–12.4 – Present information, findings, and supporting evidence clearly and logically. Mathematics N.Q.A.1 – Use units to understand and solve multi-step problems; interpret units in formulas, graphs, and data displays. N.Q.A.2 – Define appropriate quantities for descriptive modeling. N.Q.A.3 – Choose an appropriate level of accuracy based on limitations of measurement. G.SRT.C.6 – Understand and use trigonometric ratios for acute angles. G.SRT.C.8 – Use trigonometric ratios and the Pythagorean Theorem to solve right triangles in applied problems. S.ID.B.6 – Represent data involving two quantitative variables and analyze relationships between those variables.		
Career Readiness, Life Literacies, and Key Skills	9.4.12.CI.1 – Demonstrate the ability to reflect, analyze, and use creative skills and ideas. 9.4.12.CT.1 – Identify problem-solving strategies used in the development of an innovative product or practice. 9.4.12.CT.2 – Explain the potential benefits of collaborating to enhance critical thinking and problem solving. 9.4.12.CT.4 – Participate in planning for course-based projects and determine strategies that contribute to effective outcomes.		
Computer Science and Design Thinking	8.2.12.ED.1 – Use research to design and create a product or system that addresses a problem and make modifications based on input from potential consumers. 8.2.12.ED.2 – Create scaled engineering drawings for a new product or system and make modifications to increase optimization based on feedback. 8.2.12.ED.3 – Evaluate several models of the same type of product and make recommendations for a new design based on a cost-benefit analysis. 8.2.12.ED.5 – Evaluate the effectiveness of a product or system based on requirements, specifications, and constraints, including safety, reliability, economics, environmental concerns, manufacturability, maintenance, and ergonomics. 8.2.12.ED.6 – Analyze the effects of changing resources when designing a specific product or system, including materials, energy, tools, capital, and labor.		
Modifications			
Multi-Lingual Learners	Students with Special Needs	At-Risk	Gifted and Talented

● Pre-teach unit-specific vocabulary including equilibrium, resultant force, reaction force, tension, compression, stress, strain, buckling, truss, joint, load, and structural failure using diagrams, photographs, physical models, and demonstrations. ● Provide annotated free-body diagrams and color-code forces, vector components, tension members, and compression members. ● Provide sentence frames for explaining structural behavior, predicting failure, comparing materials, and defending engineering design decisions. ● Pair technical vocabulary with hands-on demonstrations so students can physically observe tension, compression, deformation, and structural failure. ● Provide visual step-by-step directions for CAD modeling, laser cutting, 3D printing, fabrication, and load-testing procedures. ● Allow students to demonstrate understanding through labeled diagrams, CAD models, physical prototypes, oral explanations, videos, and demonstrations in addition to extended written responses. ● Provide translated directions and digital translation tools when appropriate.	● Provide guided free-body diagram templates, vector-resolution organizers, equation reference sheets, and step-by-step method-of-joints examples. ● Break structural analysis problems and the Engineering Design Performance Assessment into clearly defined milestones: analyze, sketch, calculate, CAD, fabricate, test, analyze failure, and redesign. ● Provide extended time for structural calculations, CAD development, fabrication, assembly, and load-testing activities as specified by individual plans. ● Use physical structural models before introducing abstract diagrams and mathematical representations of tension, compression, and equilibrium. ● Provide partially completed diagrams or structural calculations when appropriate so students can focus on the targeted physics concept. ● Provide adaptive hand tools, jigs, clamps, fixtures, or alternative fabrication methods when needed for safe and equitable workshop participation. ● Allow collaborative fabrication while assessing	● Reinforce prerequisite mathematics involving algebra, proportional reasoning, measurement, geometry, vectors, and basic trigonometry before applying these skills to structural analysis. ● Use small-scale physical structures and demonstrations to make abstract concepts such as equilibrium, load paths, tension, and compression concrete. ● Provide scaffolded free-body diagram, vector, and method-of-joints practice before requiring independent structural analysis. ● Break the structural engineering challenge into short, graded checkpoints with clear completion deadlines. ● Provide CAD templates or partially developed models when appropriate while still requiring students to make meaningful engineering decisions. ● Assign clearly defined roles during collaborative fabrication and load testing to promote active participation and accountability. ● Conduct frequent engineering design conferences to identify incomplete work, misconceptions, or fabrication problems before they become barriers to project completion. ● Allow students to revise calculations, CAD models, and engineering documentation following feedback. ● Emphasize prototype improvement rather than initial success so that structural failure during testing	● Require more sophisticated structural analysis, including analysis of multiple joints, reaction forces, alternative load conditions, and predicted failure locations. ● Challenge students to optimize structures using a quantitative strength-to-weight ratio rather than maximum load alone. ● Require comparison of multiple structural geometries before selecting a final design. ● Incorporate additional constraints involving material quantity, cost, sustainability, fabrication time, or maximum structural mass. ● Extend material investigations to include quantitative stress-strain analysis and comparison of material performance. ● Encourage advanced CAD modeling, parametric design, simulation, or structural-analysis tools when available. ● Require students to predict the location and mode of structural failure before destructive load testing and defend the prediction mathematically.
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	individual understanding through engineering notebooks, calculations, conferences, or oral explanations. • Provide organizational checklists and frequent teacher conferences during the multi-stage structural design project. • Implement all accommodations specified in student IEPs and 504 plans.	becomes evidence for redesign rather than the end of the project.	• Challenge students to redesign failed structural components while adding no additional material. • Encourage investigation of advanced structural concepts such as gussets, cross-bracing, moment of inertia, factor of safety, composite structures, or biomimetic structural design. • Provide opportunities to act as engineering consultants during peer design reviews while requiring evidence-based recommendations rather than simply providing solutions.
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Applied Physics and Engineering

Unit 4: Machines in Motion - Torque, Rotation, & Mechanical Systems

Anchoring Phenomena: How can engineers use a relatively small input force to lift, move, launch, or control a much larger load?

Related Phenomena:

Why is it easier to open a door by pushing near the handle rather than near the hinge?
 Why does a longer wrench make it easier to loosen a bolt?
 How can gears increase torque while decreasing rotational speed?
 Why do bicycles use different-sized gears?
 How do cranes lift loads much heavier than the force supplied by an individual component?
 How do pulleys and levers provide mechanical advantage?
 Why does changing the position of a fulcrum change the force needed to lift an object?
 How do robotic arms control loads at different distances from a pivot?
 How do gear ratios affect speed and torque?
 Why do some rotating systems become unstable when mass is unevenly distributed?
 How can engineers minimize friction and energy losses in mechanical systems?

How do machines trade force, distance, speed, and torque to accomplish useful tasks?

Pacing: 7 Weeks

New Jersey Student Learning Standards (NJSLS)

HS-PS3-1 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.

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 motion of particles (objects) and energy associated with the relative position of particles (objects).

HS-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

HS-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Science & Engineering Practices	Disciplinary Core Ideas	Cross-Cutting Concepts
Asking Questions and Defining Problems - Ask questions about how force, lever arm, mass distribution, friction, and component arrangement affect the performance of mechanical systems. - Define mechanical engineering problems by identifying criteria and constraints related to load, motion, torque, speed, efficiency, materials, safety, and manufacturability. Developing and Using Models - Develop and use diagrams, mathematical models, CAD assemblies, simulations, and physical prototypes to represent mechanical systems. - Use models to predict torque, rotational motion, mechanical advantage, energy transfer, and system performance. Planning and Carrying Out Investigations	PS2.A: Forces and Motion - Forces can change the motion of objects and components within mechanical systems. - The effect of a force depends on its magnitude, direction, and point of application. - Forces applied at a distance from an axis of rotation can produce rotational effects. - Balanced and unbalanced forces and torques influence the translational and rotational behavior of mechanical systems. PS3.A: Definitions of Energy - Energy can be associated with the motion and position of objects within a mechanical system. - Mechanical systems can store, transfer, and transform energy as components move and interact. - The motion of macroscopic objects contributes to the energy of an engineered system. PS3.B: Conservation of Energy and Energy Transfer	Cause and Effect - Changes in applied force, lever arm, gear ratio, pulley configuration, friction, or mass distribution produce predictable changes in mechanical-system performance. - Cause-and-effect relationships can be investigated through controlled testing of mechanical components and prototypes. - Engineering modifications can produce intended and unintended effects on torque, speed, mechanical advantage, and efficiency. Scale, Proportion, and Quantity - Quantitative relationships among force, distance, torque, rotational speed, gear ratio, work, energy, mechanical advantage, and efficiency

- Plan and conduct investigations involving torque, rotational equilibrium, center of mass, gears, levers, pulleys, mechanical advantage, work, and efficiency. - Develop controlled procedures for testing fabricated mechanical components and complete systems. Analyzing and Interpreting Data - Analyze quantitative data related to force, torque, rotational speed, displacement, mechanical advantage, work, energy, and efficiency. - Compare predicted mechanical performance with experimental results. - Use testing data to identify friction, misalignment, deformation, energy losses, and other factors limiting system performance. Using Mathematics and Computational Thinking - Apply mathematical relationships to calculate torque, gear ratios, mechanical advantage, work, energy, and efficiency. - Use mathematical and computational models to predict the performance of mechanical systems. - Use CAD and other digital tools to model interacting components and optimize dimensions, gear ratios, lever arms, and mechanical configurations. Constructing Explanations and Designing Solutions - Construct evidence-based explanations of how torque, rotational motion, mechanical advantage, and energy	- Energy cannot be created or destroyed, but it can be transferred between objects and transformed from one form to another. - Changes in the energy of one component of a mechanical system are related to changes in other components and to energy transferred into or out of the system. - Work transfers energy when forces cause objects or mechanical components to move. - Real mechanical systems transfer some energy to the surrounding environment through friction, deformation, sound, and thermal energy. PS3.D: Energy in Chemical Processes and Everyday Life - Energy can be converted from one form to another to accomplish useful tasks. - Engineered devices use energy transformations to produce desired motion or mechanical output. - The effectiveness of an engineered device can be evaluated by considering how successfully it transforms available energy into useful output. ETS1.A: Defining and Delimiting Engineering Problems - Mechanical engineering problems are defined through quantitative and qualitative criteria and constraints. - Design requirements may include load capacity, torque, speed, efficiency, size, materials, cost, safety, reliability, and manufacturability. - Complex mechanical problems can be divided into smaller problems involving individual components and subsystems. ETS1.B: Developing Possible Solutions - Multiple mechanical solutions can be developed and compared using scientific principles, mathematical analysis, CAD models, simulations, and physical prototypes.	are used to analyze mechanical systems. - Proportional relationships can be used to predict how changes in gear size, lever-arm length, or pulley arrangement affect system performance. - Scale and dimensional accuracy are important when designing CAD models and fabricating interacting mechanical components. Systems and System Models - Mechanical devices are systems composed of interacting components such as gears, shafts, pulleys, levers, bearings, linkages, and structural supports. - Mathematical models, diagrams, CAD assemblies, simulations, and physical prototypes can be used to predict and evaluate system behavior. - Changes to one component can affect force, motion, energy transfer, and performance throughout the entire mechanical system. Energy and Matter - Energy is transferred and transformed as it moves through a mechanical system. - Mechanical devices convert input energy into useful output while some energy is transferred to the surroundings through friction, heat, sound, and deformation. - Tracking energy through a system allows engineers to evaluate
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transformations govern machine operation. - Design, fabricate, test, and refine mechanical devices that convert or transfer energy to accomplish a specified task. - Optimize mechanical solutions based on quantitative performance data and established criteria and constraints. Engaging in Argument from Evidence - Defend mechanical design decisions using calculations, testing data, physics principles, and engineering evidence. - Evaluate competing mechanical solutions based on torque, mechanical advantage, efficiency, reliability, safety, cost, and manufacturability. - Use evidence from prototype testing to justify design modifications and optimization decisions. Obtaining, Evaluating, and Communicating Information - Obtain and evaluate scientific and technical information about gears, pulleys, levers, mechanical systems, energy transfer, and machine design. - Communicate engineering solutions through engineering notebooks, technical drawings, CAD models, calculations, data displays, physical prototypes, and presentations. - Present and defend final mechanical-system designs using scientific reasoning, mathematical analysis, and experimental evidence.	- Engineers use models and prototypes to evaluate interactions among gears, levers, pulleys, shafts, linkages, and other components. - Testing individual components and subsystems provides evidence that informs development of the complete mechanical system. ETS1.C: Optimizing the Design Solution - Mechanical systems are improved through iterative cycles of design, fabrication, testing, analysis, and redesign. - Quantitative testing can identify sources of friction, energy loss, misalignment, excessive force, or mechanical inefficiency. - Optimization requires balancing competing criteria such as torque, speed, mechanical advantage, efficiency, reliability, safety, material use, cost, and manufacturability.	efficiency and identify opportunities for improvement. Structure and Function - The geometry, dimensions, arrangement, and materials of mechanical components influence how they function. - Gear size, lever-arm length, pulley arrangement, shaft diameter, component alignment, and other design features affect the performance of a mechanical system. - Engineers modify component structure to achieve desired outcomes involving torque, speed, mechanical advantage, stability, and reliability. Stability and Change - Balanced forces and torques produce stable mechanical conditions, while unbalanced forces and torques produce changes in translational or rotational motion. - Mechanical systems can become less stable or efficient because of friction, wear, misalignment, deformation, or changing loads. - Iterative testing and redesign allow engineers to improve system stability, reliability, efficiency, and performance.
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Essential Questions	Student Learning Objectives	Suggested Tasks/Activities	Evidence of Learning (Assessment)
- How do engineers use forces to produce and control rotational motion? - How do the magnitude, direction, and point of application of a force affect torque? - How does the location of a system's center of mass affect its balance and stability? - How can rotational equilibrium be predicted using forces and torques? - How are linear motion and rotational motion related? - How does the distribution of mass affect the rotational behavior of a mechanical system? - How do engineers use levers, pulleys, gears, wheels and axles, and other mechanisms to create mechanical advantage? - How do gear ratios affect torque, rotational speed, and the performance of a mechanical system? - How do machines trade force, distance, speed, and torque to accomplish useful work? - How is energy transferred and transformed within mechanical systems? - Why can no real mechanical system be 100% efficient? - How do friction, deformation, and other energy losses affect the performance of engineered	Student will be able to: - Explain how force, distance from a pivot, and angle of application affect torque. - Calculate torque in mechanical and engineered systems. - Analyze balanced and unbalanced torques and determine conditions for rotational equilibrium. - Identify and determine the center of mass of objects and explain its effect on balance and stability. - Describe relationships among linear motion, angular displacement, angular velocity, and rotational motion. - Explain how the distribution of mass affects the rotational behavior of a mechanical system. - Analyze how levers, wheels and axles, pulleys, and gears modify force, motion, and mechanical advantage. - Calculate ideal and actual mechanical advantage for simple and compound machines. - Determine gear ratios and predict their effects on rotational speed, direction, and torque.	Torque Investigation: Vary force magnitude and distance from a pivot to experimentally determine how each variable affects torque. Door and Wrench Investigation: Analyze familiar tools and mechanisms to investigate why changing the lever arm changes rotational effect. Rotational Equilibrium Lab: Use meter sticks, masses, pivots, and force measurements to predict and experimentally verify balanced torques. Center of Mass Challenge: Determine the center of mass of regular and irregular objects and investigate how center-of-mass location affects stability. Balancing Design Challenge: Design and fabricate a balanced system with an intentionally offset or adjustable center of mass. Rotational Motion Investigation: Measure and analyze angular displacement, angular velocity, rotational period, and the relationship between linear and rotational motion. Rotational Inertia Investigation: Compare objects with different mass distributions to investigate how rotational inertia affects changes in rotational motion. Lever Investigation: Construct and test different classes of levers to	Formative Assessments - Engineering notebook entries documenting torque calculations, mechanical-system analysis, sketches, design decisions, and testing results - Torque and rotational-equilibrium problem sets - Exit tickets on torque, center of mass, rotational motion, work, energy, mechanical advantage, and efficiency - Lever-arm and rotational-equilibrium laboratory analysis - Center-of-mass investigation and reflection - Gear-ratio calculations and performance predictions - Pulley and lever mechanical-advantage calculations - Work, energy, and efficiency calculations - CAD model progress checks - Prototype component testing and design reviews - Peer engineering critiques - Teacher observation of safe and appropriate fabrication practices Performance Assessments

machines? • How can engineers use mathematical models, CAD, and physical prototypes to predict the performance of mechanical systems? • How can testing data be used to improve the torque, mechanical advantage, efficiency, reliability, and performance of a machine? • How do engineers balance performance, safety, materials, cost, manufacturability, and efficiency when designing mechanical systems? • How does iterative design, fabrication, testing, and redesign lead to more effective mechanical solutions?	• Calculate work and analyze energy transfers and transformations within mechanical systems. • Calculate and compare the efficiency of mechanical devices using experimental data. • Explain how friction, deformation, and other energy losses affect the performance and efficiency of machines. • Analyze mechanical systems as interacting components that transfer forces, motion, and energy. • Establish quantitative and qualitative criteria and constraints for a mechanical engineering problem. • Develop engineering sketches, technical drawings, and CAD models of mechanical components and systems. • Apply torque, mechanical advantage, energy, and rotational-motion principles to predict the performance of a proposed design. • Select appropriate materials, dimensions, gear ratios, lever arms, pulleys, and other mechanical components based on design requirements. • Safely fabricate mechanical components using 3D	compare input force, output force, lever arm, and mechanical advantage. • Pulley Systems Lab: Build fixed, movable, and compound pulley systems and compare theoretical and actual mechanical advantage. • Gear Ratio Investigation: Use physical or fabricated gears to investigate how gear ratios affect rotational speed, direction, and torque. • 3D-Printed Gear Challenge: Design gears in CAD, fabricate them using 3D printers, assemble a functioning gear train, and compare predicted and actual performance. • Laser-Cut Mechanism Challenge: Design and fabricate a simple mechanical linkage, cam, gear train, or lever system using laser-cut components. • Work and Energy Investigation: Measure input and output work in mechanical systems and trace energy transfers through the device. • Mechanical Efficiency Lab: Calculate the efficiency of levers, pulley systems, gears, or lifting mechanisms and investigate sources of energy loss. • Friction Investigation: Examine how bearings, bushings, lubrication, alignment, surface contact, and material selection affect mechanical efficiency. • Mechanical Advantage Optimization: Modify a mechanical system to increase force output while	• Torque Investigation: Students experimentally investigate the relationship among applied force, lever-arm distance, and torque and compare measured results with mathematical predictions. • Rotational Equilibrium Investigation: Students calculate and experimentally verify the conditions required for balanced torques. • Gear Train Performance Assessment: Students design or assemble a gear system, calculate gear ratios, and compare predicted rotational speed and torque relationships with observed performance. • Mechanical Advantage Investigation: Students construct and test lever and/or pulley systems and compare theoretical and actual mechanical advantage. • Energy & Efficiency Investigation: Students measure input and output work in a mechanical system, calculate efficiency, and identify sources of energy loss. • CAD Mechanical Assembly: Students create
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	printers, laser cutters, and appropriate workshop tools. • Assemble fabricated components into a functional mechanical system. • Conduct controlled testing to measure force, torque, displacement, rotational speed, mechanical advantage, and/or efficiency. • Compare predicted mechanical performance with experimental results and explain discrepancies using evidence. • Evaluate engineering trade-offs involving force, speed, torque, efficiency, materials, cost, safety, reliability, and manufacturability. • Use quantitative testing data to redesign and optimize a mechanical system. • Maintain an engineering notebook documenting calculations, CAD development, fabrication, testing, design revisions, and performance data. • Communicate and defend a final mechanical design using physics principles, mathematical analysis, experimental evidence, and engineering reasoning.	documenting the corresponding trade-offs in distance or speed. • Reverse Engineering Activity: Disassemble or analyze an appropriate mechanical device to identify gears, levers, pulleys, shafts, bearings, linkages, and other components and explain their functions. • Real-World Machine Analysis: Analyze systems such as bicycles, cranes, elevators, transmissions, winches, robotic arms, or manufacturing equipment to identify applications of torque and mechanical advantage. • CAD Mechanical Assembly: Create digital models of interacting mechanical components and verify clearances, dimensions, alignment, and range of motion before fabrication. • Prototype Component Testing: Fabricate and test gears, axles, levers, pulleys, joints, or other components before incorporating them into a complete system. • Mechanical Systems Design Challenge: Develop a system capable of lifting, moving, manipulating, or controlling a specified load while meeting defined engineering constraints. • Prototype Fabrication: Use 3D printers, laser cutters, and appropriate workshop tools to manufacture components and assemble a functional mechanical system.	a functional digital model containing interacting mechanical components and demonstrate appropriate dimensions, clearances, alignment, and range of motion. • Prototype Testing: Students quantitatively evaluate a fabricated mechanical system using measurements such as input force, output force, torque, rotational speed, displacement, lifting capacity, mechanical advantage, and efficiency. • Engineering Design Notebook: Students document physics calculations, sketches, CAD development, fabrication decisions, testing data, failures, and iterative improvements. Summative Assessment: Mechanical Systems Engineering Challenge Students will design, analyze, fabricate, test, and optimize a mechanical device capable of lifting, moving, manipulating, or controlling a specified load while satisfying established engineering criteria and constraints. Students will: • Establish quantitative and qualitative design criteria and constraints.
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		● Quantitative Performance Testing: Measure variables such as input force, output force, torque, lifting capacity, rotational speed, displacement, mechanical advantage, and efficiency. ● Predicted vs. Actual Performance Analysis: Compare theoretical calculations and CAD/design predictions with measured prototype performance. ● Failure and Performance Analysis: Identify friction, deformation, slipping, gear misalignment, component failure, excessive torque, or other factors limiting system performance. ● Iterative Redesign: Modify CAD models, gear ratios, lever arms, pulley arrangements, materials, or component geometry based on testing evidence. ● Engineering Notebook: Document calculations, sketches, CAD development, fabrication decisions, testing data, failures, modifications, and design iterations. ● Engineering Design Review: Conduct peer critiques in which students defend mechanical design choices using torque, energy, mechanical advantage, and performance data. ● Technical Presentation: Demonstrate the completed mechanical system and explain how physics principles informed its design, fabrication, testing, and optimization.	● Apply torque, rotational motion, work, energy, mechanical advantage, and efficiency principles to the proposed solution. ● Determine appropriate lever arms, gear ratios, pulley arrangements, or other mechanical components. ● Develop engineering sketches and technical drawings. ● Create a CAD model or digital mechanical assembly. ● Fabricate components using 3D printers, laser cutters, and appropriate workshop tools. ● Assemble a functional mechanical prototype. ● Predict the system's performance mathematically before testing. ● Conduct controlled performance testing and collect quantitative data. ● Compare theoretical and actual mechanical advantage and efficiency. ● Identify friction, deformation, alignment, material limitations, or other sources of energy loss and reduced performance. ● Redesign and optimize the
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			mechanical system using testing evidence. • Present and defend the final design using physics, mathematics, and engineering evidence. Final Deliverables: Engineering Design Notebook; physics and engineering calculations; CAD model/technical drawings; fabricated mechanical system; quantitative performance-testing data; theoretical vs. actual performance analysis; design-iteration documentation; final engineering presentation; individual reflection.
Interdisciplinary Connections	<u>ELA</u> RI.CR.11–12.1 – Cite strong and thorough textual evidence to support analysis of informational and technical texts. RI.CI.11–12.2 – Determine and analyze central ideas of complex informational and technical texts. W.AW.11–12.1 – Write arguments to support claims using valid reasoning and relevant evidence. W.WR.11–12.5 – Conduct short and sustained research projects to answer questions and solve problems. SL.PE.11–12.1 – Initiate and participate effectively in collaborative discussions. SL.PI.11–12.4 – Present information, findings, and supporting evidence clearly and logically. <u>Mathematics</u> N.Q.A.1 – Use units as a way to understand problems and guide the solution of multi-step problems; choose and interpret units consistently in formulas, graphs, and data displays. N.Q.A.2 – Define appropriate quantities for the purpose of descriptive modeling. N.Q.A.3 – Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. F.IF.B.4 – Interpret functions that arise in applications in terms of the context. S.ID.B.6 – Represent data involving two quantitative variables and analyze relationships between those variables.		
Career Readiness, Life Literacies, and Key Skills	9.4.12.CI.1 – Demonstrate the ability to reflect, analyze, and use creative skills and ideas. 9.4.12.CT.1 – Identify problem-solving strategies used in the development of an innovative product or practice. 9.4.12.CT.2 – Explain the potential benefits of collaborating to enhance critical thinking and problem solving. 9.4.12.CT.4 – Participate in planning for course-based projects and determine strategies that contribute to effective outcomes.		
Computer Science and Design Thinking	8.2.12.ED.1 – Use research to design and create a product or system that addresses a problem and make modifications		

based on input from potential consumers. 8.2.12.ED.2 – Create scaled engineering drawings for a new product or system and make modifications to increase optimization based on feedback. 8.2.12.ED.3 – Evaluate several models of the same type of product and make recommendations for a new design based on a cost-benefit analysis. 8.2.12.ED.5 – Evaluate the effectiveness of a product or system based on factors related to its requirements, specifications, and constraints, including safety, reliability, economic considerations, quality control, environmental concerns, manufacturability, maintenance and repair, and ergonomics. 8.2.12.ED.6 – Analyze the effects of changing resources when designing a specific product or system, including materials, energy, tools, capital, and labor. 8.2.12.NT.2 – Redesign an existing product to improve form or function.			
Modifications			
Multi-Lingual Learners	Students with Special Needs	At-Risk	Gifted and Talented
- Pre-teach unit-specific vocabulary including torque, pivot, fulcrum, lever arm, center of mass, rotational equilibrium, angular velocity, gear ratio, mechanical advantage, work, energy, power, and efficiency using diagrams, physical models, and demonstrations. - Pair technical vocabulary with hands-on demonstrations of gears, pulleys, levers, rotating systems, and mechanical devices. - Provide annotated diagrams and color-coded models showing input/output forces, direction of rotation, lever arms, gear interactions, and energy transfers. - Provide sentence frames for explaining mechanical-system behavior, comparing designs, analyzing performance, and defending engineering decisions. - Provide visual, step-by-step instructions for CAD modeling,	- Provide guided calculation templates for torque, mechanical advantage, gear ratios, work, energy, and efficiency. - Use physical models of gears, pulleys, levers, and rotating systems before moving to abstract mathematical representations. - Break the Mechanical Systems Engineering Challenge into defined milestones: investigate, calculate, sketch, CAD, fabricate, assemble, test, analyze, and redesign. - Provide extended time for calculations, CAD development, fabrication, assembly, and prototype testing as specified in individual plans. - Provide partially completed diagrams, data tables, CAD	- Reinforce prerequisite mathematics involving algebra, ratios, proportional reasoning, measurement, unit conversions, and graph interpretation before applying these skills to mechanical systems. - Use familiar machines and physical demonstrations to make torque, rotational motion, mechanical advantage, and energy transfer concrete. - Scaffold multi-step torque, gear-ratio, mechanical-advantage, and efficiency calculations with worked examples and guided practice. - Divide CAD and fabrication projects into short, graded checkpoints with clearly defined deadlines and deliverables. - Provide starter CAD files or partially developed mechanical assemblies when appropriate while requiring students to make meaningful design decisions. - Assign specific engineering-team	- Extend torque analysis to systems involving multiple forces, changing lever arms, compound mechanisms, or multiple rotational components. - Challenge students to design compound machines that integrate gears, pulleys, levers, linkages, cams, or other mechanisms. - Require optimization for multiple competing variables such as maximum load, rotational speed, mechanical advantage, efficiency, mass, or cost. - Require comparison of theoretical and actual mechanical advantage and a quantitative explanation of efficiency losses. - Encourage advanced CAD assemblies incorporating

gear design, assembly, fabrication, and prototype testing. ● Allow students to demonstrate understanding through labeled diagrams, CAD models, physical prototypes, demonstrations, videos, and oral explanations in addition to written responses. ● Provide translated directions and digital translation tools when appropriate.	templates, or calculation organizers when appropriate. ● Provide adaptive hand tools, jigs, clamps, fixtures, or alternative fabrication methods to support safe participation. ● Allow collaborative fabrication while assessing individual understanding through engineering notebooks, calculations, teacher conferences, demonstrations, or oral explanations. ● Provide organizational checklists and frequent teacher conferences during multi-stage fabrication projects. ● Implement all accommodations specified in student IEPs and 504 plans.	roles during fabrication, assembly, and testing to promote participation and accountability. ● Conduct frequent design conferences to identify calculation, fabrication, alignment, or project-management problems before they prevent successful completion. ● Allow revision of calculations, CAD models, prototypes, and engineering documentation following feedback and testing. ● Emphasize troubleshooting and redesign so that mechanical failure is treated as evidence for improvement rather than unsuccessful project completion.	moving joints, gear trains, tolerances, clearances, and parametric components. ● Challenge students to design and fabricate custom gears, pulleys, cams, linkages, bearings, or other mechanical components. ● Incorporate additional constraints involving material quantity, energy efficiency, manufacturing time, sustainability, reliability, or cost. ● Require students to predict system performance before fabrication and quantitatively evaluate discrepancies after testing. ● Encourage investigation of advanced concepts such as rotational inertia, angular momentum, power transmission, compound gear ratios, frictional losses, or gear-train efficiency. ● Provide opportunities to serve as engineering consultants during peer design reviews while requiring recommendations to be supported by calculations and testing evidence.
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Applied Physics and Engineering**Unit 5: Engineering Earth and Space: Energy, Systems, and Technology**

Anchoring Phenomena: How can engineers use physics and technology to understand, monitor, and respond to changes in Earth and space systems?

Related Phenomena:

Why do satellites remain in orbit instead of falling directly back to Earth or flying off into space?

How does changing a satellite's altitude affect its orbital motion and usefulness?

How can satellites observe features on Earth that cannot be easily measured from the ground?

How do remote-sensing instruments use electromagnetic radiation to collect information about Earth's surface and atmosphere?

Why do different surfaces on Earth absorb, reflect, and emit different amounts of energy?

Why does Earth's surface temperature depend on the balance between incoming solar energy and outgoing energy?

How can changes in atmospheric composition affect Earth's energy balance?

Why are coastal and inland climates different even when they occur at similar latitudes?

How does thermal energy move through Earth's atmosphere, oceans, and interior?

How can convection help explain large-scale motion within Earth systems?

Why are earthquakes and volcanoes concentrated in particular regions of Earth?

How can seismic waves be used to infer properties of Earth's interior?

Why do some structures withstand earthquakes better than others?

How do engineers use sensors to detect and monitor earthquakes, weather, temperature, radiation, and other environmental conditions?

How can networks of sensors provide a more complete model of an Earth system than a single measurement?

How do engineers distinguish meaningful trends from short-term variation in environmental data?

How can computer models be used to predict changes in Earth systems?

Why do scientific models sometimes produce different predictions even when they use similar data?

How can engineers evaluate the reliability and limitations of climate and Earth-system models?

How do solar panels convert incoming solar energy into useful electrical energy?

Why does the angle and orientation of a solar panel affect the amount of energy it collects?

How can a solar-tracking system increase energy collection compared with a fixed system?

How do engineers decide which renewable-energy technology is appropriate for a particular location?

How do material selection, cost, efficiency, durability, and environmental impact influence renewable-energy design?

How can technologies reduce the effects of human activity on Earth systems?

How do engineers balance energy needs with environmental impacts, economic constraints, and societal priorities?

How can technology help communities prepare for or respond to earthquakes, storms, flooding, extreme heat, or other natural hazards?

What engineering challenges must be solved before people can live and work for extended periods on the Moon or Mars?

How would differences in gravity, temperature, atmosphere, radiation, and available resources influence the design of structures or machines for another planetary body?

How can Earth-observation technologies developed for space missions also help solve problems on Earth?

How does improving the accuracy of measurements lead to better engineering decisions about Earth and space systems?

Pacing: 6 Weeks**New Jersey Student Learning Standards (NJSLS)**

HS-ESS1-4 Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.

HS-ESS1-5 Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.

HS-ESS2-1 Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.

HS-ESS2-3 Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.

HS-ESS2-4 Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS-ESS3-2 Evaluate competing design solutions for developing, conserving, managing, and utilizing energy and mineral resources based on the associated economic, social, environmental, and geopolitical costs and risks, as well as benefits.

HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on climate change and other natural systems.

HS-ESS3-5 Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

HS-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Science & Engineering Practices	Disciplinary Core Ideas	Cross-Cutting Concepts
Asking Questions and Defining Problems - Ask questions about gravitational interactions, orbital motion, Earth-system processes, energy transfer, climate patterns, natural hazards, and human impacts on Earth systems. - Define Earth and space engineering problems by identifying measurable criteria and constraints related to performance, accuracy, reliability, cost, energy use, environmental impact, and societal needs. - Refine engineering problems based on scientific evidence, available	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. - Newton's law of universal gravitation provides the physical explanation for orbital motion within the solar system. - Mathematical and computational models can be used to predict the motion of planets, moons, satellites, and other orbiting objects. ESS1.C: The History of Planet Earth - Continental rocks contain evidence of Earth's long geologic history, while much of the oceanic crust is considerably younger because it is continually	Patterns - Patterns in orbital motion, geologic evidence, seismic activity, climate data, and environmental measurements can be used to identify relationships and make predictions. - Patterns observed across large datasets can provide evidence of changes occurring within Earth systems. - Engineers use patterns in sensor and testing data to evaluate and improve technological solutions.

technology, and limitations of proposed solutions. Developing and Using Models - Develop and use physical, mathematical, and computational models to represent orbital motion and gravitational interactions. - Develop models illustrating interactions among Earth's atmosphere, hydrosphere, geosphere, biosphere, and energy systems. - Use models to explain thermal convection, Earth's energy balance, plate movement, and other large-scale Earth processes. - Develop CAD models, system diagrams, and physical prototypes to represent proposed Earth and space technologies. Planning and Carrying Out Investigations - Plan and conduct investigations involving thermal-energy transfer, solar-energy collection, environmental conditions, and Earth-system processes. - Use sensors and digital technologies to collect quantitative environmental data. - Develop controlled testing procedures to evaluate Earth and space engineering prototypes. - Identify independent, dependent, and controlled variables and consider measurement accuracy and uncertainty. Analyzing and Interpreting Data - Analyze satellite, seismic, climate, environmental, and experimental data to identify patterns, trends, relationships, and anomalies.	created and recycled through plate tectonic processes. - Patterns in the ages and locations of rocks provide evidence for past and present movements of Earth's crust. ESS2.A: Earth Materials and Systems - Earth is a dynamic system in which energy and matter move among interacting components. - Earth's systems operate across a wide range of spatial and temporal scales. - Energy originating within Earth contributes to processes that continually reshape the planet. ESS2.B: Plate Tectonics and Large-Scale System Interactions - Plate tectonics provides a framework for understanding large-scale interactions among Earth's crust, mantle, and surface. - Radioactive decay and residual energy from Earth's formation generate thermal energy within the planet. - Thermal convection and gravitational processes contribute to the movement of matter within Earth and the motion of tectonic plates. ESS2.D: Weather and Climate - Earth's climate system is driven primarily by energy from the Sun and influenced by the transfer of energy among the atmosphere, hydrosphere, geosphere, biosphere, and space. - Changes in Earth's energy budget can produce changes in climate. - Models and observational data can be used to investigate relationships among energy flows, atmospheric conditions, and climate. ESS3.A: Natural Resources - Natural resources are distributed unevenly because of past and current geologic processes.	Cause and Effect - Cause-and-effect relationships can be used to explain how gravitational interactions influence orbital motion. - Changes in energy inputs, atmospheric conditions, and interactions among Earth systems can produce changes in environmental conditions and climate. - Tectonic processes produce observable effects including earthquakes, volcanic activity, and changes in Earth's surface. - Engineering interventions can produce both intended and unintended effects within complex Earth systems. Scale, Proportion, and Quantity - Earth and space processes occur across enormous ranges of distance, time, energy, and magnitude. - Mathematical relationships can be used to analyze orbital motion, energy transfer, environmental data, and changes within Earth systems. - Scale models and simulations allow scientists and engineers to investigate systems that cannot be directly reproduced in the laboratory. - Engineers must account for differences between prototype-scale testing and actual operating conditions. Systems and System Models - Earth is composed of interacting systems, including the atmosphere,
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• Interpret graphical and numerical data representing changes in Earth systems over different spatial and temporal scales. • Compare predicted system behavior with measured data. • Analyze prototype-testing data to evaluate performance and identify opportunities for improvement. Using Mathematics and Computational Thinking • Use mathematical and computational representations to predict the motion of orbiting objects. • Apply quantitative reasoning to analyze energy transfer, environmental measurements, and Earth-system data. • Use spreadsheets, graphing tools, simulations, sensor interfaces, and other computational technologies to organize and analyze data. • Use computational models to evaluate possible outcomes of proposed Earth and space engineering solutions. Constructing Explanations and Designing Solutions • Construct evidence-based explanations for Earth-system processes using scientific models and quantitative data. • Use geoscience evidence to explain relationships among Earth's internal energy, plate movement, surface processes, and environmental change. • Design technological solutions that monitor Earth systems, reduce human impacts, address natural hazards, or accomplish an Earth/space mission.	• Resource availability influences technological development and engineering decisions. • Engineers must evaluate trade-offs when developing solutions for obtaining and using energy and mineral resources. ESS3.C: Human Impacts on Earth Systems • Human activities can alter Earth systems at local, regional, and global scales. • Technologies can be designed and refined to reduce negative environmental impacts. • Engineering solutions require consideration of environmental, economic, technological, and societal constraints. ESS3.D: Global Climate Change • Changes in atmospheric composition and other Earth-system variables can affect climate. • Global climate models and geoscience data are used to investigate relationships among Earth systems and predict possible future changes. • Scientific predictions include uncertainty and are strengthened through improved observations, data collection, and modeling. ETS1.A: Defining and Delimiting Engineering Problems • Earth and space engineering problems are defined by identifying measurable criteria and constraints. • Design requirements may include accuracy, reliability, mass, energy use, cost, environmental impact, safety, durability, and mission requirements. ETS1.B: Developing Possible Solutions • Multiple solutions can be evaluated using scientific principles, Earth-system data, mathematical models, computer simulations, CAD models, and physical prototypes.	hydrosphere, geosphere, and biosphere. • Earth and space systems can be represented using physical, mathematical, conceptual, and computational models. • Changes within one component of an Earth system can affect other components of the system. • Satellites, sensors, renewable-energy technologies, and environmental-monitoring devices are engineered systems composed of interacting components and subsystems. Energy and Matter • Energy and matter move within and among Earth systems. • Solar radiation provides a major source of energy driving processes at Earth's surface, while internal thermal energy drives many geologic processes. • Energy is absorbed, reflected, transferred, transformed, and emitted as it moves through Earth systems. • Engineers track energy inputs, transfers, transformations, and losses when evaluating renewable-energy and Earth/space technologies. Structure and Function • The structure and arrangement of components in satellites, sensors, solar-energy devices, and monitoring systems influence their function and performance.
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- Design, fabricate, test, and refine prototypes that satisfy specified criteria and constraints. Engaging in Argument from Evidence - Evaluate competing explanations and models using geoscience, satellite, climate, and experimental evidence. - Defend conclusions about Earth and space systems using quantitative evidence and scientific reasoning. - Evaluate competing engineering solutions based on performance, reliability, cost, environmental impact, safety, and societal needs. - Defend engineering design decisions using testing data, scientific principles, and documented trade-offs. Obtaining, Evaluating, and Communicating Information - Obtain and evaluate scientific and technical information about Earth systems, space systems, natural hazards, energy resources, climate, satellites, sensors, and engineering technologies. - Evaluate the reliability, limitations, uncertainty, and relevance of scientific data and technical information. - Communicate Earth and space science findings through models, graphs, data visualizations, technical writing, and presentations. - Communicate engineering solutions through engineering notebooks, CAD models, system diagrams, prototypes, testing data, technical reports, and design presentations.	- Sensors, models, and prototypes provide evidence that can inform the development of Earth and space technologies. ETS1.C: Optimizing the Design Solution - Earth and space technologies can be improved through iterative cycles of modeling, fabrication, testing, data analysis, and redesign. - Optimization requires balancing competing criteria and constraints such as performance, accuracy, reliability, energy consumption, cost, environmental impact, and societal needs.	- Materials and component geometry are selected based on environmental conditions and mission requirements. - Engineers modify the structure of technological systems to improve measurement accuracy, durability, efficiency, reliability, and performance. Stability and Change - Earth systems exhibit both periods of relative stability and changes occurring over short and long timescales. - Changes in energy flow, atmospheric conditions, tectonic activity, and human activity can influence Earth-system stability. - Long-term datasets help distinguish persistent changes from short-term variability. - Engineering systems can be monitored, tested, and redesigned in response to changing environmental conditions and performance data.
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Essential Questions	Student Learning Objectives	Suggested Tasks/Activities	Evidence of Learning (Assessment)
- How can engineers use physics and technology to observe, measure, and model Earth and space systems? - How does gravity control the motion of planets, moons, satellites, and other orbiting objects? - How can mathematical and computational models be used to predict orbital motion? - How do satellites and remote-sensing technologies allow scientists and engineers to study Earth from space? - How does energy from the Sun drive processes within Earth's atmosphere, oceans, and climate system? - How do radiation, conduction, and convection transfer energy through Earth systems? - How does the balance between incoming and outgoing energy influence Earth's climate? - How does energy within Earth's interior drive large-scale geologic processes? - What evidence allows scientists to reconstruct the movement and evolution of Earth's crust? - How can sensors, satellites, and other technologies be used to collect reliable data about changing Earth systems?	Student will be able to: - Apply gravitational principles and mathematical models to explain and predict the motion of orbiting objects. - Analyze how orbital distance, velocity, and gravitational interactions affect satellites and other objects in the solar system. - Explain how satellites, sensors, and remote-sensing technologies collect information about Earth and space systems. - Interpret satellite imagery, sensor measurements, and other geoscience data to identify patterns and changes in Earth systems. - Analyze evidence related to the movement of continental and oceanic crust and connect that evidence to plate tectonic processes. - Develop models illustrating how Earth's internal and surface processes operate across different spatial and temporal scales. - Explain how thermal energy from Earth's interior drives convection and contributes to large-scale geologic processes.	Orbital Motion Investigation: Use mathematical and computational models to investigate how gravity, orbital velocity, mass, and distance influence the motion of satellites and other orbiting objects. Satellite Mission Design: Analyze different satellite missions and determine how orbital altitude, instrumentation, power requirements, and mission purpose influence engineering design. Remote Sensing Investigation: Analyze satellite imagery and remote-sensing data to identify changes in land use, vegetation, surface temperature, ice cover, weather, or other Earth-system variables. Earth Observation Data Analysis: Collect, graph, and interpret authentic environmental or satellite data to identify patterns, trends, and anomalies. Sensor Technology Investigation: Use temperature, light, pressure, humidity, or other available sensors to collect environmental data and evaluate measurement accuracy and limitations. Environmental Monitoring System: Design and assemble a sensor-based system capable of collecting and recording data about a selected environmental variable.	Formative Assessments - Engineering notebook entries documenting Earth/space system models, data analysis, calculations, design decisions, and observations - Exit tickets addressing orbital motion, Earth systems, energy transfer, plate tectonics, climate, and technological applications - Orbital motion calculations and computational-model analysis - Satellite and remote-sensing data interpretation - Earth-system model development and revision - Plate tectonics evidence analysis - Thermal-energy transfer and convection laboratory analysis - Earth energy-budget model analysis - Environmental sensor data collection and graphing - Climate and geoscience dataset analysis - Renewable-energy calculations and performance comparisons

• How can scientists and engineers use large data sets and computational models to identify patterns and predict changes in Earth systems? • What are the limitations and uncertainties associated with models of complex Earth and space systems? • How can engineering solutions help communities monitor, prepare for, and respond to natural hazards? • How can engineers design technologies that reduce negative human impacts on Earth systems? • How can renewable-energy technologies capture and convert naturally available energy into useful forms? • How do engineers evaluate trade-offs among efficiency, cost, reliability, environmental impact, materials, and societal needs when developing energy technologies? • How can testing, data analysis, and iterative redesign improve technologies used to monitor or interact with Earth and space systems? • How do the environmental conditions of Earth, the Moon, Mars, and other planetary bodies influence engineering design? • How can technologies developed for space exploration contribute to solving engineering and environmental problems on Earth?	• Model the transfer of energy among Earth's atmosphere, hydrosphere, geosphere, and space. • Analyze how incoming solar radiation and outgoing energy influence Earth's energy balance and climate. • Use quantitative data to identify trends, patterns, relationships, and variability within Earth and climate systems. • Evaluate the strengths, limitations, and uncertainty associated with scientific and computational models of complex Earth systems. • Explain how sensors and technological systems can be used to monitor environmental conditions and natural hazards. • Design investigations that use sensors or other technologies to collect environmental data. • Analyze how engineering and technological solutions can reduce human impacts on Earth systems. • Evaluate competing solutions for managing energy and natural resources using criteria such as efficiency, cost, reliability, sustainability, and environmental impact. • Apply principles of energy transfer and transformation to renewable-energy	• Earth's Energy Budget Model: Develop a physical or computational model illustrating incoming solar radiation, reflection, absorption, and outgoing energy. • Surface Heating Investigation: Compare the absorption and emission of energy by different surfaces and materials and connect results to Earth-system processes. • Greenhouse Effect Modeling: Use models, simulations, and data to investigate how changes in atmospheric conditions influence Earth's energy balance. • Conduction, Convection, and Radiation Investigation: Conduct laboratory investigations comparing mechanisms of thermal-energy transfer and connect observations to processes occurring within Earth's atmosphere, oceans, and interior. • Convection Model: Develop and test a physical model demonstrating how temperature and density differences can produce convection within a fluid system. • Plate Motion Evidence Analysis: Analyze maps and data involving seafloor age, earthquake locations, volcanoes, magnetic patterns, and/or continental geology to evaluate evidence for plate tectonics. • Earthquake & Seismic Data Investigation: Analyze seismic-wave or earthquake-location data to investigate Earth's internal structure and tectonic activity. • Natural Hazard Engineering Case	• CAD model and engineering design progress checks • Peer design critiques and engineering conferences • Teacher observation of safe sensor, electronics, fabrication, and workshop practices Performance Assessments • Orbital Systems Investigation: Students use mathematical or computational models to predict and explain the motion of orbiting objects. • Earth Systems Modeling Assessment: Students develop and defend a model showing interactions among energy, matter, and processes within Earth systems. • Plate Tectonics Evidence Analysis: Students evaluate geoscience evidence to explain past and current movement of Earth's crust. • Earth Energy Balance Investigation: Students analyze models and data describing incoming solar energy, energy transfer within Earth systems, and outgoing radiation. • Earth Observation Data Analysis: Students analyze satellite, climate, seismic, or other geoscience
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How can physics, Earth science, and engineering work together to develop more sustainable and resilient technologies?	technologies. - Design and evaluate technological solutions for monitoring, mitigating, or responding to Earth-system challenges. - Establish quantitative and qualitative criteria and constraints for an Earth or space engineering problem. - Develop engineering sketches, technical drawings, CAD models, computational models, or system diagrams for a proposed solution. - Select appropriate sensors, materials, fabrication processes, and technological components based on design requirements. - Safely fabricate prototype components using 3D printers, laser cutters, electronics, sensors, and appropriate workshop tools. - Collect, organize, graph, and analyze quantitative data generated during prototype or system testing. - Compare predicted system performance with experimental results and explain discrepancies using evidence. - Evaluate engineering trade-offs involving performance, energy use, cost, safety, reliability, environmental impact,	Study: Investigate how engineers design buildings, infrastructure, monitoring systems, or warning technologies to reduce risks associated with earthquakes, flooding, storms, or other natural hazards. Shake-Table Mini-Challenge: Design and test a small structural system under simulated seismic loading, then modify the design based on observed performance. Solar Energy Investigation: Measure how angle, orientation, shading, and other variables influence the energy output of a small solar-energy system. Solar Tracking Design Challenge: Design, fabricate, and test a mechanism or mounting system intended to improve solar-energy collection. Renewable Energy Comparison: Evaluate renewable-energy technologies using criteria including energy output, efficiency, cost, reliability, location, environmental impact, and resource availability. Engineering Trade-Off Analysis: Compare competing technological solutions to an Earth-system problem and evaluate trade-offs among performance, environmental impact, cost, reliability, and societal needs. Climate/Earth-System Data Investigation: Analyze long-term datasets and distinguish long-term trends from short-term variability. Model Evaluation Activity: Compare	datasets to identify patterns, trends, relationships, and limitations. Environmental Sensor Investigation: Students collect environmental measurements using appropriate sensors, analyze the resulting data, and evaluate measurement reliability. Engineering Solutions Analysis: Students compare competing technological solutions to an Earth-system challenge using established criteria and constraints. CAD/Prototype Design Assessment: Students develop a digital model and/or fabricated prototype of an Earth or space technology and justify major design decisions. Summative Assessment: Earth Observation & Space Systems Engineering Challenge Students will design, model, fabricate, test, and refine a technological system intended to observe, measure, monitor, or respond to an Earth or space system. The project may take the form of a model satellite, Earth-observation payload, environmental-monitoring
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	materials, and societal needs. ● Use testing data and scientific evidence to refine and optimize an Earth or space technology solution. ● Maintain an engineering notebook documenting research, scientific models, calculations, CAD development, fabrication, data collection, testing, and design iterations. ● Communicate and defend an engineering solution using Earth and space science concepts, physics principles, quantitative evidence, and engineering reasoning.	predictions from multiple Earth-system models or scenarios and identify assumptions, uncertainties, limitations, and evidence supporting each model. ● Planetary Engineering Comparison: Compare environmental conditions on Earth, the Moon, and/or Mars and determine how gravity, temperature, atmosphere, radiation, and resources affect engineering design. ● Extreme Environment Materials Challenge: Evaluate or test materials for use in a simulated Earth or space environment based on thermal, structural, mass, durability, or other design constraints. ● CAD Earth/Space Technology Design: Develop a digital model of a satellite component, sensor housing, solar-energy device, environmental monitoring station, or other Earth/space technology. ● Digital Fabrication: Use 3D printers, laser cutters, electronics, sensors, and appropriate workshop tools to fabricate components for an Earth or space engineering solution. ● Prototype Testing: Develop a controlled testing procedure and collect quantitative evidence about the performance of the fabricated system. ● Data-Driven Redesign: Modify the engineering solution based on sensor data, experimental results, model predictions, and established design criteria. ● Engineering Notebook: Document	station, sensor package, solar-energy system, natural-hazard monitoring device, or comparable teacher-approved engineering solution. Students will: ● Define the Earth or space problem or mission the technology will address. ● Establish quantitative and qualitative design criteria and constraints. ● Research the relevant Earth/space science and physics principles. ● Identify the variables that must be measured, monitored, or controlled. ● Select appropriate sensors, materials, components, and fabrication processes. ● Develop engineering sketches, system diagrams, and technical drawings. ● Create a CAD model of the device, housing, mounting system, or other appropriate components. ● Fabricate prototype components using 3D printers, laser cutters, electronics, sensors, and/or appropriate workshop tools. ● Assemble a functional prototype or engineering model. ● Develop a controlled procedure for evaluating
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		scientific research, Earth-system models, calculations, data analysis, sketches, CAD development, fabrication, testing, and iterative redesign. ● Technical Design Review: Participate in peer engineering reviews and defend design decisions using Earth science concepts, physics principles, quantitative evidence, and engineering criteria. ● Final Technical Presentation: Communicate the function, scientific basis, design process, testing results, limitations, and proposed improvements of an Earth or space technology solution.	system performance. ● Collect, organize, graph, and analyze quantitative testing data. ● Evaluate measurement accuracy, reliability, uncertainty, and system limitations. ● Compare actual performance with predicted performance and established design criteria. ● Evaluate trade-offs involving mass, energy use, cost, durability, accuracy, reliability, environmental impact, and mission requirements. ● Refine the design using scientific evidence and testing data. ● Present and defend the final engineering solution. Final Deliverables ● Engineering Design Notebook ● Earth/Space Science Research and Scientific Model ● Design Criteria and Constraints ● Engineering Calculations and Data Analysis ● Technical Drawings/System Diagrams ● CAD Model ● Fabricated Prototype or Engineering Model ● Sensor/Performance
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			Testing Data • Analysis of Error, Uncertainty, and Design Limitations • Design Iteration Documentation • Final Technical Report • Engineering Presentation/Design Defense • Individual Reflection
Interdisciplinary Connections	<u>ELA</u> RI.CR.11–12.1 – Cite strong and thorough textual evidence to support analysis of informational and technical texts. RI.CI.11–12.2 – Determine and analyze central ideas in complex informational texts. RI.MF.11–12.6 – Synthesize complex information across multiple sources and formats to develop ideas, resolve conflicting information, or develop an interpretation. RI.CT.11–12.8 – Analyze and reflect on documents of historical and scientific significance, including texts proposing scientific or technical advancements. W.AW.11–12.1 – Write arguments supported by valid reasoning and relevant and sufficient evidence. W.IW.11–12.2 – Write informative/explanatory texts, including scientific procedures, experiments, and technical processes, to communicate complex information clearly and accurately. W.WR.11–12.5 – Conduct research to answer questions or solve problems. SL.PE.11–12.1 – Participate effectively in collaborative discussions. SL.PI.11–12.4 – Present information, findings, and supporting evidence clearly and logically. <u>Mathematics</u> N.Q.A.1 – Use units as a way to understand problems and guide the solution of multi-step problems; choose and interpret units consistently in formulas, graphs, and data displays. N.Q.A.2 – Define appropriate quantities for the purpose of descriptive modeling. N.Q.A.3 – Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. F.IF.B.4 – Interpret functions that arise in applications in terms of the context. S.ID.A.1 – Represent data with plots on the real number line. S.ID.B.6 – Represent data involving two quantitative variables and analyze relationships between those variables. S.ID.C.9 – Distinguish between correlation and causation.		
Career Readiness, Life Literacies, and Key Skills	9.4.12.CI.1 – Demonstrate the ability to reflect, analyze, and use creative skills and ideas. 9.4.12.CT.1 – Identify problem-solving strategies used in the development of an innovative product or practice. 9.4.12.CT.2 – Explain the potential benefits of collaborating to enhance critical thinking and problem solving. 9.4.12.DC.8 – Explain how increased network connectivity and computing capabilities of everyday objects allow for		

	innovative technological approaches to climate protection. 9.4.12.GCA.1 – Collaborate with individuals to analyze a variety of potential solutions to climate-change effects and determine why some solutions may work better than others. 9.4.12.IML.1 – Compare search browsers and recognize features that allow for filtering of information.		
Computer Science and Design Thinking	8.2.12.ED.1 – Use research to design and create a product or system that addresses a problem and make modifications based on feedback. 8.2.12.ED.2 – Create scaled engineering drawings for a new product or system and make modifications to increase optimization based on feedback. 8.2.12.ED.3 – Evaluate several models of the same type of product and make recommendations for a new design based on a cost-benefit analysis. 8.2.12.ED.5 – Evaluate the effectiveness of a product or system based on requirements, specifications, and constraints, including safety, reliability, economics, environmental concerns, manufacturability, maintenance, and ergonomics. 8.2.12.ED.6 – Analyze the effects of changing resources when designing a specific product or system, including materials, energy, tools, capital, and labor. 8.2.12.ETW.3 – Identify a complex, global environmental or climate-change issue and develop a systemic plan of investigation. 8.2.12.ETW.4 – Research historical tensions between environmental and economic considerations as driven by human needs and wants in the development of a technological product and present the competing viewpoints.		
Modifications			
Multi-Lingual Learners	Students with Special Needs	At-Risk	Gifted and Talented
● Pre-teach unit-specific vocabulary including orbit, gravity, satellite, remote sensing, radiation, convection, tectonic plate, climate, energy budget, sensor, calibration, model, uncertainty, and sustainability using visuals, physical models, diagrams, and demonstrations. ● Provide annotated diagrams and visual models of orbital systems, Earth’s layers, plate boundaries, energy flows, satellite systems, and environmental-monitoring technologies. ● Pair complex Earth and space concepts with simulations, animations, maps, satellite	● Provide guided notes, vocabulary supports, annotated diagrams, data-analysis templates, and equation/reference sheets. ● Break complex Earth-system and orbital models into individual components before requiring students to analyze interactions among the complete systems. ● Chunk large satellite, climate, seismic, or environmental datasets into manageable sections and highlight relevant variables when appropriate. ● Provide partially completed	● Reinforce prerequisite skills involving graph interpretation, proportional reasoning, scientific notation, measurement, unit conversions, and data analysis before applying them to Earth and space systems. ● Use physical models and local environmental observations before moving to large-scale or abstract Earth and space processes. ● Provide structured data-analysis protocols that guide students through identifying variables, patterns, trends, anomalies, and evidence-based conclusions. ● Use smaller datasets before transitioning students to authentic satellite, seismic, environmental, or	● Extend orbital analysis to compare different satellite altitudes, orbital periods, mission requirements, and gravitational conditions. ● Require analysis of larger or more complex authentic satellite, climate, seismic, or environmental datasets. ● Challenge students to evaluate uncertainty, measurement error, model limitations, and competing interpretations of Earth-system data. ● Require integration of multiple sensors into an environmental-monitoring

imagery, and hands-on demonstrations before requiring extended written explanations. ● Provide sentence frames for interpreting scientific data, describing patterns, comparing models, explaining cause-and-effect relationships, and defending engineering decisions. ● Provide graphic organizers for analyzing satellite, climate, seismic, and environmental datasets. ● Provide visual, step-by-step directions for sensor setup, data collection, CAD modeling, electronics, fabrication, and prototype testing. ● Allow students to demonstrate understanding through labeled models, diagrams, data visualizations, CAD models, prototypes, oral explanations, and demonstrations in addition to written responses. ● Provide translated directions, bilingual resources, and digital translation tools when appropriate.	graphs, data tables, system diagrams, and computational models to reduce unnecessary processing demands while maintaining the targeted science objective. ● Break the Earth & Space Systems Engineering Challenge into defined milestones: research, define the problem, analyze data, sketch, CAD/model, fabricate, test, analyze, redesign, and communicate. ● Provide extended time for data analysis, computational modeling, CAD development, fabrication, programming/sensor setup, and assessments as specified in individual plans. ● Provide adaptive tools, accessible electronics, jigs, fixtures, or alternative fabrication methods when needed. ● Allow collaborative fabrication and sensor setup while assessing individual scientific understanding through engineering notebooks, data analysis, conferences, or oral explanations. ● Implement all accommodations specified in student IEPs and 504 plans.	climate datasets. ● Break computational modeling and engineering projects into short, graded checkpoints with clear deadlines and deliverables. ● Provide starter CAD files, sensor code, spreadsheet templates, or partially developed system models when appropriate while requiring meaningful student decisions. ● Assign clearly defined engineering-team roles during sensor development, fabrication, data collection, and testing. ● Conduct frequent project conferences to identify misconceptions, incomplete work, technical problems, or organizational barriers. ● Allow students to revise models, data analyses, CAD designs, prototypes, and technical explanations following feedback. ● Connect Earth and space engineering problems to recognizable applications such as weather forecasting, GPS, natural-hazard monitoring, renewable energy, and environmental sensing.	or Earth-observation system. ● Encourage students to program microcontrollers or data-logging systems to automate data collection and analysis. ● Extend CAD work to include complete satellite payloads, sensor housings, deployable mechanisms, solar-panel mounts, or other mission-specific components. ● Incorporate additional engineering constraints involving mass, power consumption, data accuracy, communication, durability, environmental conditions, sustainability, or cost. ● Require quantitative comparison of multiple competing technological solutions before selecting a final design. ● Challenge students to develop computational models or simulations and compare model predictions with observational or experimental data. ● Extend planetary engineering problems by requiring designs adapted to Moon or Mars conditions involving reduced gravity, extreme
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			temperatures, atmospheric differences, radiation, or limited resources. ● Encourage independent investigation of aerospace engineering, geophysics, remote sensing, climate science, renewable-energy engineering, or environmental engineering. ● Provide opportunities to serve as technical consultants during peer design reviews while requiring recommendations to be supported by scientific evidence and quantitative data.
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Applied Physics and Engineering

Unit 6: Engineering the Future - Bridge Design Capstone

Anchoring Phenomena: How can engineers design a bridge that safely carries the greatest possible load while minimizing material, mass, and cost?

Related Phenomena:

- Why can two bridges constructed from the same amount of material support dramatically different loads?
- Why are triangles so common in bridge structures?
- How does a load travel from a bridge deck through structural members and ultimately into the ground?
- Why are some bridge members under tension while others are under compression?
- How does the location of a load affect forces throughout a bridge?
- Why do long, thin compression members tend to buckle?
- Why do bridge failures frequently begin at joints and connections?
- How does changing truss geometry alter the forces experienced by individual members?
- Why can adding material to a bridge sometimes produce little improvement in structural efficiency?
- How can removing material sometimes improve a bridge's strength-to-weight ratio?
- Why do engineers use different bridge types for different spans, loads, locations, and environmental conditions?

- How do material properties influence bridge performance?
- How accurately can free-body diagrams and mathematical calculations predict the behavior of a physical bridge?
- Why might an actual fabricated bridge fail at a different load or location than predicted?
- How do manufacturing tolerances and fabrication quality affect structural performance?
- Why do engineers use a factor of safety when designing real structures?
- How do engineers determine whether additional structural strength is worth additional mass and cost?
- How can destructive testing provide useful information for future designs?
- How do engineers learn from structural failures?
- How can computer modeling and CAD improve a bridge before physical fabrication begins?
- How do engineers balance safety, strength, cost, material use, aesthetics, sustainability, and constructability?
- How does iterative testing and redesign produce safer and more efficient structures?

Pacing: 8-10 Weeks

New Jersey Student Learning Standards (NJSLS)

Essential Questions	Student Learning Objectives	Suggested Tasks/Activities	Evidence of Learning (Assessment)
• How can physics and engineering principles be integrated to design a safe, efficient, and effective bridge? • How do Newton's Laws help engineers predict how a bridge will respond to applied loads? • How are forces transferred from an applied load through a bridge and into its supports? • How can free-body diagrams and mathematical models be used to predict structural performance? • How do tension and compression affect individual bridge members? • How does truss geometry influence force distribution, stability, and structural strength? • How do material properties affect the strength, stiffness, durability, and failure of a bridge? • How can engineers predict where and how a bridge is most likely to	Student will be able to: • Apply Newton's Laws and principles of static equilibrium to analyze forces acting on a bridge. • Construct and interpret free-body diagrams representing applied loads, reaction forces, and forces within structural systems. • Resolve forces into appropriate vector components and use mathematical models to analyze structural behavior. • Identify and calculate forces acting on bridge members in tension and compression. • Apply the method of joints and other appropriate structural-analysis techniques to analyze truss systems. • Trace load paths through a	• Bridge Engineering Case Studies: Analyze real-world bridge designs to compare structural systems, materials, span requirements, load paths, and engineering constraints. • Bridge Failure Case Study: Investigate a historical structural failure and identify contributing factors involving forces, materials, connections, fabrication, loading, or engineering decisions. • Bridge Type Comparison: Compare truss, beam, arch, suspension, cable-stayed, and other bridge systems and evaluate their advantages and limitations for different applications. • Capstone Design Brief: Analyze the project requirements and establish measurable criteria and constraints for span, dimensions, materials, mass, load capacity, cost, and fabrication.	Formative Assessments • Engineering notebook checks documenting research, calculations, sketches, design decisions, fabrication progress, testing, and redesign • Bridge-type research and comparison • Bridge failure case-study analysis • Criteria and constraints development • Preliminary concept sketches and design alternatives • Design decision matrix • Free-body diagram and reaction-force calculations • Load-path analysis • Method-of-joints/truss-analysis calculations • Tension and compression

fail? • Why might the actual performance of a fabricated bridge differ from its mathematical or digital model? • How do joints, connections, fabrication accuracy, and construction quality influence overall structural performance? • How can engineers maximize load capacity while minimizing bridge mass and material use? • How can strength-to-weight ratio be used to evaluate and compare structural efficiency? • How can CAD, mathematical analysis, and computer modeling improve a bridge design before fabrication? • How can controlled load testing provide evidence about the strengths and weaknesses of a design? • What can engineers learn from structural deformation and failure? • How can testing data and failure analysis be used to improve and optimize a bridge design? • How do engineers balance competing criteria and constraints such as safety, strength, cost, weight, material use, aesthetics, sustainability, and constructability? • Why are optimization and trade-offs necessary when there is no single “perfect” engineering solution? • How does iterative design improve	bridge from the point of application to the supports. • Explain how bridge geometry influences force distribution, stability, strength, and structural efficiency. • Analyze how material properties influence structural performance, deformation, buckling, and failure. • Calculate and compare load capacity and strength-to-weight ratio as measures of bridge performance. • Define a complex bridge-design problem by establishing quantitative and qualitative criteria and constraints. • Break the bridge-design problem into manageable subproblems involving geometry, materials, members, joints, supports, fabrication, and testing. • Research and compare bridge types and select an appropriate structural system based on project requirements. • Generate and evaluate multiple bridge-design concepts before selecting a final solution. • Develop scaled engineering sketches and technical drawings that accurately	• Concept Generation: Develop multiple preliminary bridge concepts through sketches and annotated engineering diagrams before selecting a final design. • Design Decision Matrix: Compare proposed designs using weighted criteria such as strength, mass, material use, manufacturability, reliability, aesthetics, and anticipated performance. • Load Path Analysis: Trace how applied loads travel through the bridge deck, structural members, joints, and supports. • Free-Body Diagram Analysis: Construct free-body diagrams showing applied loads and support reactions for the proposed bridge. • Reaction Force Calculations: Calculate forces at bridge supports under specified loading conditions. • Truss Analysis: Apply the method of joints and appropriate vector analysis to calculate forces in selected bridge members. • Tension/Compression Mapping: Create a color-coded diagram identifying members predicted to experience tension and compression. • Failure Prediction: Identify likely failure locations and predict whether failure will result from tension, compression, buckling, connection failure, or another structural mechanism. • Material Selection Analysis: Evaluate available materials based on strength, stiffness, mass, consistency,	member identification • Material-selection justification • Joint and structural-member testing • Scaled technical drawing review • CAD model progress checks • Predicted failure analysis • Fabrication-plan review • Teacher conferences at major design milestones • Peer engineering design critiques • Workshop safety and fabrication-skill observations Performance Assessments • Structural Analysis Assessment: Students analyze their proposed bridge using free-body diagrams, reaction forces, tension/compression identification, and appropriate truss calculations. • Material and Component Testing Assessment: Students test representative materials, structural members, and/or connections and use quantitative evidence to justify design decisions. • Pre-Fabrication Design Review: Students present their proposed bridge, calculations, CAD model,
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the performance and reliability of engineered structures? - How can engineers use scientific evidence, mathematical analysis, and testing data to defend a final design solution? How does the bridge design capstone demonstrate the integration of physics, mathematics, technology, fabrication, and the engineering design process developed throughout the course?	communicate the proposed design. - Create a detailed CAD model of the bridge and use digital modeling or simulation tools to evaluate the design where appropriate. - Use physics calculations, structural analysis, and modeling to predict bridge performance before fabrication. - Predict the maximum load, likely failure location, and expected mode of failure of the proposed bridge. - Select materials and fabrication processes based on structural properties, project constraints, manufacturability, and anticipated performance. - Safely and accurately use laser cutters, 3D printers, measurement tools, hand tools, and appropriate workshop equipment to fabricate bridge components. - Apply precision measurement, appropriate tolerances, and quality-control procedures during fabrication and assembly. - Conduct controlled load testing and collect quantitative data describing bridge performance. - Identify structural	cost, manufacturability, and expected structural performance. Connection/Joint Testing: Fabricate and test sample joints or connections before finalizing the bridge design. Structural Member Testing: Test representative components under tension and/or compression and use the resulting data to inform final design decisions. Scaled Technical Drawings: Produce dimensioned engineering drawings showing bridge geometry, member locations, connections, and overall dimensions. CAD Bridge Modeling: Create a complete digital model of the proposed bridge prior to fabrication. Digital/Computational Design Analysis: Use available simulation or modeling tools to evaluate structural behavior and compare design alternatives. Pre-Fabrication Design Review: Present calculations, CAD models, material selections, anticipated load paths, and failure predictions for approval before construction. Fabrication Planning: Develop a manufacturing plan identifying materials, tools, fabrication sequence, tolerances, assembly methods, and safety considerations. Bridge Component Fabrication: Use laser cutters, 3D printers, and/or appropriate workshop tools to manufacture bridge components. Precision Assembly: Construct the bridge while applying dimensional	materials, criteria and constraints, anticipated load paths, and predicted structural performance before receiving approval to fabricate. CAD & Technical Drawing Assessment: Students produce accurate scaled drawings and a complete digital bridge model that satisfies dimensional and fabrication requirements. Fabrication & Quality-Control Assessment: Students demonstrate precision measurement, appropriate tool use, safe fabrication practices, dimensional accuracy, alignment, assembly quality, and compliance with design specifications. Predicted Performance Assessment: Before load testing, students submit a predicted maximum load, likely failure location, expected failure mode, and supporting scientific and mathematical reasoning. Controlled Load-Test Assessment: Students conduct and document a standardized bridge load test, collecting quantitative performance data and observations of
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	deformation and failure resulting from tension, compression, buckling, joint failure, material failure, or inadequate load distribution. • Compare predicted structural performance with actual load-testing results and explain discrepancies using scientific and engineering evidence. • Evaluate the bridge using multiple performance criteria, including load capacity, strength-to-weight ratio, material efficiency, dimensional compliance, fabrication quality, and safety. • Analyze trade-offs among strength, mass, material use, cost, aesthetics, sustainability, safety, and constructability. • Use testing evidence and failure analysis to redesign and optimize structural components or the overall bridge. • Compare the performance of initial and revised designs to determine whether modifications resulted in measurable improvement. • Maintain a comprehensive engineering notebook documenting research, calculations, sketches, CAD development, material decisions, fabrication procedures, testing data,	tolerances, alignment procedures, and quality-control checks. • Mass and Material Audit: Track bridge mass and material usage throughout construction and compare actual values with design predictions. • Pre-Test Inspection: Inspect dimensions, joints, alignment, symmetry, workmanship, and compliance with all project specifications before load testing. • Predicted Performance Report: Before testing, submit the predicted maximum load, predicted failure location, predicted failure mode, and supporting calculations. • Controlled Load Testing: Apply progressively increasing loads while observing and documenting structural behavior. • Load/Deflection Data Collection: Measure load and structural deformation where practical to identify changes in bridge behavior prior to failure. • Destructive Testing: Continue controlled loading to structural failure when appropriate, documenting the sequence and location of failure. • Failure Documentation: Photograph/video the bridge before, during, and after testing and identify the initial and subsequent failure locations. • Failure Analysis: Compare observed failure with predicted behavior and determine why the bridge performed	deformation and failure. • Failure Analysis Assessment: Students identify the initial failure point and mode and explain the bridge's performance using force distribution, tension, compression, buckling, material behavior, connections, and fabrication quality. • Optimization/Redesign Assessment: Students use testing evidence to revise the design and demonstrate how proposed or fabricated changes should improve structural efficiency. Benchmark • Linkit! Form C Summative Assessment Culminating Engineering Design Performance Assessment – EDPA 6 Bridge Design Capstone Challenge Students will research, design, mathematically analyze, digitally model, fabricate, test, evaluate, and optimize a bridge that satisfies established engineering criteria and constraints. The final bridge should be evaluated using multiple measures rather than maximum load alone: • Compliance with design criteria and constraints
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	failure analysis, and design iterations. - Communicate and defend the final bridge design using physics principles, mathematical analysis, CAD documentation, testing data, and engineering reasoning. - Reflect on the complete engineering design process and evaluate how scientific knowledge, mathematical modeling, fabrication skills, testing, failure, and iteration contributed to the final solution.	as it did. Strength-to-Weight Analysis: Calculate structural efficiency and compare bridge performance using load capacity relative to bridge mass. Class Performance Data Analysis: Compare bridge designs across the class to identify patterns among geometry, mass, material use, fabrication quality, and structural performance. Redesign Challenge: Modify the CAD model and structural design based on testing evidence while addressing identified weaknesses. Optimization Challenge: Improve structural efficiency while limiting or reducing total material use rather than simply adding reinforcement. Second-Iteration Testing: Fabricate and test revised components or a second bridge iteration when time and materials permit. Engineering Notebook: Maintain comprehensive documentation of research, calculations, sketches, CAD development, material decisions, fabrication, testing data, failure analysis, and redesign. Peer Engineering Review: Participate in formal design critiques and provide evidence-based feedback on competing bridge solutions. Final Technical Report: Produce a professional report documenting the design problem, physics analysis, engineering process, fabrication, results, failure analysis, and optimization.	- Accuracy and completeness of physics/structural analysis - Maximum load capacity - Strength-to-weight ratio - Material efficiency - Accuracy of predicted performance and failure - CAD and technical-drawing quality - Fabrication precision and workmanship - Appropriate and safe use of fabrication technologies - Quality of quantitative testing data - Depth of failure analysis - Evidence of iterative redesign and optimization - Engineering notebook/documentation - Final technical communication and design defense Final Deliverables Engineering Design Notebook/Portfolio Design Brief with Criteria and Constraints Research and Bridge-Type Analysis Concept Sketches and Design Alternatives Free-Body Diagrams and Structural Calculations Tension/Compression and Load-Path Analysis Material/Component Testing Data
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		● Capstone Design Defense: Present and defend the final bridge design using calculations, CAD models, testing evidence, and engineering reasoning. ● Individual Capstone Reflection: Evaluate how the final project demonstrates growth in physics, engineering design, CAD, fabrication, problem solving, collaboration, testing, and iterative improvement across the course.	● Scaled Technical Drawings ● Final CAD Model ● Fabrication Plan ● Completed Physical Bridge ● Pre-Test Performance and Failure Prediction ● Load-Testing Data ● Strength-to-Weight Analysis ● Photographic/Video Documentation of Testing and Failure ● Post-Test Failure Analysis ● Redesign/Optimization Documentation ● Final Technical Report ● Formal Engineering Design Defense ● Individual Capstone Reflection
Interdisciplinary Connections	<u>ELA</u> RI.CR.11–12.1 – Cite strong and thorough textual evidence to support analysis of informational and technical texts. RI.CI.11–12.2 – Determine and analyze central ideas in complex informational and technical texts. W.AW.11–12.1 – Develop arguments supported by valid reasoning and relevant and sufficient evidence. W.IW.11–12.2 – Write informative/explanatory texts to communicate complex scientific and technical information clearly and accurately. W.WR.11–12.5 – Conduct research to answer questions or solve problems. SL.PE.11–12.1 – Participate effectively in collaborative discussions. SL.PI.11–12.4 – Present information, findings, and supporting evidence clearly and logically. <u>Mathematics</u> N.Q.A.1 – Use units to understand and solve multi-step problems; interpret units consistently in formulas, graphs, and data displays. N.Q.A.2 – Define appropriate quantities for descriptive modeling. N.Q.A.3 – Choose an appropriate level of accuracy based on limitations of measurement. G.SRT.C.6 – Understand and use trigonometric ratios for acute angles. G.SRT.C.8 – Use trigonometric ratios and the Pythagorean Theorem to solve right triangles in applied problems. S.ID.B.6 – Represent data involving two quantitative variables and analyze relationships between those variables.		

Career Readiness, Life Literacies, and Key Skills	9.4.12.CI.1 – Demonstrate the ability to reflect, analyze, and use creative skills and ideas. 9.4.12.CT.1 – Identify problem-solving strategies used in the development of an innovative product or practice. 9.4.12.CT.2 – Explain the potential benefits of collaborating to enhance critical thinking and problem solving. 9.4.12.CT.4 – Participate in planning for course-based projects and determine strategies that contribute to effective outcomes.		
Computer Science and Design Thinking	8.2.12.ED.1 – Use research to design and create a product or system that addresses a problem and make modifications based on feedback. 8.2.12.ED.2 – Create scaled engineering drawings for a new product or system and make modifications to increase optimization based on feedback. 8.2.12.ED.3 – Evaluate several models of the same type of product and make recommendations for a new design based on a cost-benefit analysis. 8.2.12.ED.5 – Evaluate the effectiveness of a product or system based on requirements, specifications, and constraints, including safety, reliability, economics, environmental concerns, manufacturability, maintenance, and ergonomics. 8.2.12.ED.6 – Analyze the effects of changing resources when designing a specific product or system, including materials, energy, tools, capital, and labor. 8.2.12.NT.2 – Redesign an existing product to improve form or function.		
Modifications			
Multi-Lingual Learners	Students with Special Needs	At-Risk	Gifted and Talented
- Pre-teach and reinforce capstone vocabulary including load path, reaction force, tension, compression, equilibrium, buckling, truss, joint, constraint, optimization, structural efficiency, factor of safety, and failure mode using diagrams, photographs, models, and demonstrations. - Provide annotated bridge diagrams with color-coded tension/compression members, applied loads, reaction forces, and load paths. - Provide visual examples of bridge types, structural failures, technical drawings, CAD models, and completed engineering documentation. - Provide sentence frames for	- Provide guided templates for free-body diagrams, reaction-force calculations, method-of-joints analysis, strength-to-weight calculations, and failure analysis. - Break the capstone into clearly defined milestones: research → criteria/constraints → concepts → structural analysis → CAD → design review → fabrication → testing → failure analysis → redesign → presentation. - Provide a visual project calendar, milestone checklist, and intermediate deadlines for the multi-week capstone.	- Review prerequisite concepts involving Newton's Laws, free-body diagrams, vectors, equilibrium, tension/compression, truss analysis, measurement, and basic trigonometry before independent application. - Provide exemplars of successful engineering notebooks, CAD drawings, structural calculations, and failure analyses. - Break the long-term capstone into short, graded checkpoints so that project completion does not depend on one final submission. - Require regular engineering notebook checks to monitor progress and identify misconceptions early. - Provide structured design conferences at major decision points	- Require more extensive structural analysis involving multiple joints, reaction forces, alternative loading conditions, or comparison of competing truss configurations. - Require quantitative optimization using strength-to-weight ratio and material efficiency rather than maximum load alone. - Challenge students to minimize bridge mass or material quantity while maintaining a specified minimum load capacity. - Require prediction of maximum load, initial

explaining design decisions, predicting structural performance, analyzing failure, comparing alternatives, and defending redesign decisions. • Provide graphic organizers for criteria/constraints analysis, design comparisons, testing data, and failure analysis. • Provide visual, step-by-step directions for major project milestones while maintaining student responsibility for engineering decisions. • Allow students to communicate understanding through annotated drawings, calculations, CAD models, physical prototypes, oral explanations, videos, and demonstrations in addition to extended written responses. • Provide translated directions and digital translation tools when appropriate.	• Provide extended time for calculations, CAD development, fabrication, assembly, technical writing, and presentations as specified in individual plans. • Provide partially completed calculation organizers, technical-drawing templates, or CAD reference models when appropriate without removing essential engineering decision-making. • Allow assistive technology for technical writing, calculations, CAD navigation, and engineering documentation. • Provide adaptive hand tools, jigs, clamps, fixtures, measurement devices, or alternative fabrication methods when required for safe workshop participation. • Allow collaborative fabrication while assessing individual understanding through engineering notebooks, calculations, design conferences, failure analysis, and the final design defense. • Provide additional teacher check-ins before fabrication and destructive testing to verify understanding and safety. • Implement all accommodations specified in student IEPs and 504 plans.	before students proceed to fabrication. • Use small-scale component and joint tests to allow students to experience success and gather useful evidence before constructing the complete bridge. • Provide CAD starter templates or structural-analysis organizers when appropriate while maintaining student responsibility for the final design. • Assign clearly defined team responsibilities for analysis, documentation, fabrication, quality control, and testing while requiring individual accountability. • Provide opportunities to revise calculations, CAD models, technical documentation, and design decisions following feedback. • Treat prototype failure as engineering evidence and provide structured failure-analysis protocols to guide redesign rather than grading primarily on maximum bridge strength. • Use multiple measures of capstone success, including scientific reasoning, design process, fabrication quality, testing, documentation, and improvement—not simply load capacity.	failure location, and failure mode with quantitative justification before testing. • Incorporate additional design constraints involving cost, sustainability, fabrication time, material quantity, aesthetics, or factor of safety. • Require comparison of multiple CAD/design alternatives using a quantitative decision matrix. • Encourage advanced CAD modeling, parametric design, structural simulation, or finite-element analysis when appropriate tools are available. • Extend analysis to concepts such as buckling, stress concentration, moment of inertia, factor of safety, redundancy, or connection efficiency. • Challenge students to redesign the bridge following destructive testing while adding little or no additional material. • Require quantitative comparison between the original and redesigned bridge to demonstrate measurable optimization. • Encourage investigation of innovative bridge forms,
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Course Resources
PhET Interactive Simulations – https://phet.colorado.edu/ The Physics Classroom – https://www.physicsclassroom.com/ TeachEngineering – https://www.teachengineering.org/ Concord Consortium – https://learn.concord.org/ Autodesk Education – https://www.autodesk.com/education/ Autodesk Fusion – https://www.autodesk.com/products/fusion-360/ Tinkercad – https://www.tinkercad.com/ Onshape Education – https://www.onshape.com/en/education/ Desmos Graphing Calculator – https://www.desmos.com/calculator CODAP – https://codap.concord.org/ NASA STEM Engagement – https://www.nasa.gov/learning-resources/ NASA Science: Earth – https://science.nasa.gov/earth/ NASA Earthdata – https://www.earthdata.nasa.gov/ NASA Eyes – https://eyes.nasa.gov/ NOAA – https://www.noaa.gov/ NOAA National Centers for Environmental Information – https://www.ncei.noaa.gov/ NOAA Climate.gov – https://www.climate.gov/ USGS – https://www.usgs.gov/ USGS Earthquake Hazards Program – https://earthquake.usgs.gov/ USGS Educational Resources – https://www.usgs.gov/educational-resources Federal Highway Administration – https://highways.dot.gov/ American Society of Civil Engineers – https://www.asce.org/ American Institute of Steel Construction – https://www.aisc.org/

Occupational Safety and Health Administration (OSHA) – <https://www.osha.gov/>

New Jersey PEOSH – <https://www.nj.gov/health/workplacehealthandsafety/peosh/>

New Jersey Department of Education – <https://www.nj.gov/education/>

New Jersey Student Learning Standards – <https://www.nj.gov/education/standards/>