Science and Innovation

A Boeing/Teaching Channel Partnership

SPY GLIDERS

Teacher Handbook

Teaching Channel

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The Boeing Company and Teaching Channel teamed in 2014 to create problem-based curricula inspired by science and engineering innovations at Boeing and informed by globally competitive science, math, and literacy standards. This two-week curriculum module and the companion video series are designed to help teachers in grades 4–8 integrate the engineering design process, aligned to science standards, into their classrooms. The collection of Teaching Channel curricula is one part of a collection of K–12 education resources intended to mark Boeing's centennial anniversary and prepare the next generation of innovators.

The materials created by this collaboration were taught by the authoring teachers in Puget Sound and Houston, and in 2015, a second group of teachers taught the lessons and provided feedback to improve the modules. As part of a second iteration of the modules, the senior science editor at Teaching Channel worked with Achieve to integrate the teachers' feedback while more closely aligning the modules to The Next Generation Science Standards (NGSS) call for significant shifts in the way science is taught and learned. In 2016, a panel of science experts from around the country convened for a two-day training with Achieve to learn how to incorporate the Educators Evaluating the Quality of Instructional Products (EQuIP) Rubric for Science. As part of the iterative process of improvement, the expert reviewers then completed an EQuIP Rubric for each module. Teaching Channel's senior science editor combined the reviewers input to create a third iteration of the modules that promotes a close alignment to standards while honoring the original expertise of the authoring teachers and engineers.

Partners at both the University of Washington's Institute for Science and Math as well as Educate Texas were instrumental in teacher recruitment for this project. Teachers and engineers in the project received training from learning scientists at the University of Washington's Institute for Science and Math Education, led by Dr. Philip Bell. He and his team also created a design template to support curricula development to promote alignment to standards and research on science learning and teaching.

Please note that the resource links provided in these lessons are intended as helpful illustrations to teachers adapting the unit for their classrooms and are not an endorsement of specific products or organizations.

Spy Gliders

Background and Overview

Unmanned Aerial Vehicles are becoming more common in many areas of the world. This module calls for students to design an unmanned aerial vehicle capable of carrying a payload over a given distance. As students design their gliders, they consider the forces acting on the glider. The engineering design process, forces of flight, and materials engineering are key topics throughout this module.

Module Overview

Unmanned aerial vehicles (UAVs) are air vehicles that lack onboard passengers and crew. They can be autonomous drones or remotely piloted vehicles. While one could argue that the modern drone was invented near the end of World War I (see Kettering Bug), drones have only recently been integrated into many aspects of military and civilian life.

Unit Authors

- **Julia Ward**, Seattle Public Schools
- **Ken Dunkelberg**, Boeing Engineer, Everett, WA
- **Paul Smith**, Boeing Engineer, Everett, WA
- **Kate Cook Whitt,** Teaching Channel, Senior Science Editor

Many civilian uses exist, including, but not limited to:

- Aerial surveying of crops
- Search and rescue operations
- Counting wildlife
- Delivering medical supplies to remote or otherwise inaccessible regions
- Surveillance

Military uses include:

- Reconnaissance
- Target and decoy
- Combat
- Research and development

In this module, students develop possible solutions to the engineering design problem of developing a UAV capable of carrying a payload over a given distance. Students select a specific use for their glider (reconnaissance, delivering supplies, and so forth). They then test glider designs and materials. Students experiment with adding payloads to their gliders. Finally, students optimize their glider designs.

As students design their gliders, they explore the impact of the forces acting on the glider. In particular, students investigate how changes in weight impact a glider's flight. Students test and revise their solutions, and justify their design revisions with evidence from previous tests and science ideas.

Spy Gliders

Background and Overview

Engineering Design in the Module

Gliders can be many different sizes and made of many different materials. Students select materials to create their gliders. They manipulate the placement of additional weight on the body to study its impact on the flight of the glider. They use this iterative process to design and construct another glider capable of supporting a payload. Students record and document their engineering process and iterative designs in the Spy Gliders Student Handbook.

Sequencing

Spy Gliders is intended as a middle school module. This module is designed to help students make progress on four performance expectations: MS-PS2-2, MS-ETS1-1, MS-ETS1-3, and MS-ETS1-4. The performance expectations address the engineering design process and forces.

Within the middle school sequence, this module can be used during the development of MS-PS2-2. Students should already have exposure to MS-PS2-4. In addition, students should have had some exposure to MS-PS2-2 and should have figured out that the change in an object's motion depends on the sum of the forces acting on the object. In this module, students figure out that a change in an object's motion also depends on the mass of the object.

Students should have already mastered the ***performance expectations***, ***disciplinary core ideas***, ***science and engineering practices***, ***and crosscutting concepts*** included in 5th-grade Physical Science and Engineering Design.

- Students should have mastered 3-PS2-1 and 3-PS2-2, which address the effects of balanced and unbalanced forces on the motion of an object. Students should already have made significant progress with MS-PS2-4 and figured out that gravitational interactions are attractive and depend on the masses of interacting objects.
- Beyond the aforementioned performance expectations, students should have already demonstrated deep conceptual understanding for all of the 3-5 Engineering Design performance expectations and associated science and engineering practices, disciplinary core ideas, and crosscutting concepts.
- Students should have made grade-appropriate progress on the following science and engineering practices: Asking Questions and Defining Problems, Developing and Using Models, Planning and Carrying Out Investigations, Analyzing and Interpreting Data, and Constructing Explanations and Designing Solutions.
- Students should also have made grade-appropriate progress on the following crosscutting concepts: Influence of Engineering, Technology, and Science on Society and the Natural World and Cause and Effect.

Performance Expectations

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

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Connecting to the Next Generation Science Standards

The lessons and activities outlined in this module are one step in the learning progression toward reaching the performance expectations listed below. Additional supporting lessons and activities will be required.

Specific connections between the performance expectations, three dimensions, and classroom activities are articulated at the beginning of every lesson.

Important Note

The grade level and associated performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts identified throughout the unit were selected to align with the Next Generation Science Standards. In classrooms using local or state standards, this unit may fall within a different grade band and may address different standards. Teachers should adapt this unit to meet local and state needs.

Furthermore, teachers should adapt the unit to extend student learning to additional grade levels, performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts to meet student needs.

Performance Expectations	
The lessons and activities in this module contribute toward building understanding of the following *engineering* performance expectations: MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved. **The lessons and activities in this module contribute toward building understanding of the following *physical science* performance expectations:** MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.	
Dimension	**NGSS Element**
Science and Engineering Practices	**Asking Questions and Defining Problems** • Define a design problem that can be solved through the development of an object, tool, process, or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. **Developing and Using Models** • Develop a model to predict and/or describe phenomena. • Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs.

	Planning and Carrying Out Investigations • Plan an investigation individually and collaboratively and in the design identify independent and dependent variables and controls, what tools are needed to do the gathering, and how many data are needed to support a claim. **Analyzing and Interpreting Data** • Analyze and interpret data to determine similarities and differences in findings. **Constructing Explanations and Designing Solutions** • Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process, or system.
Disciplinary Core Ideas	**ETS1.A: Defining and Delimiting Engineering Problems** • The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge likely to limit possible solutions. **ETS1.B: Developing Possible Solutions** • A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. • Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. • Models of all kinds are important for testing solutions. **ETS1.C: Optimizing the Design Solution** • Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. • The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. **PS2.A: Force and Motion** • The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.
Crosscutting Concepts	**Influence of Engineering, Technology, and Science on Society and the Natural World** • The use of technologies and limitations on their use are driven by individual and societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. **Cause and Effect** • Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Connections to the Common Core State Standards

In addition to connecting to the *Next Generation Science Standards*, this module can support student growth in multiple *Common Core State Standards.* This module can be easily adapted to support growth in the following standards:

English Language Arts

- CCSS.ELA-Literacy.W.6.1: Write arguments to support claims with clear reasons and relevant evidence.
- CCSS.ELA-Literacy.SL.6.1: Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 6 topics, texts, and issues, building on others' ideas and expressing their own clearly.
- CCSS.ELA-Literacy.SL.6.4: Present claims and findings, sequencing ideas logically and using pertinent descriptions, facts, and details to accentuate main ideas or themes; use appropriate eye contact, adequate volume, and clear pronunciation.

Mathematics

- CCSS.Math.Content.6.SP.A.2. Understand that a set of data collected to answer a statistical question has a distribution which can be described by its center, spread, and overall shape.
- CCSS.Math.Content.6.SP.A.3. Recognize that a measure of center for a numerical data set summarizes all of its values with a single number, while a measure of variation describes how its values vary with a single number.

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Module Storyline

This module is designed as a coherent set of learning experiences that motivate a progressive building of understanding of disciplinary core ideas, science and engineering practices, and crosscutting concepts. The following storyline demonstrates how ideas are built across the lessons. You may find it helpful to continually reference the storyline to help frame lessons.

Driving Question:
How can we engineer a glider that can carry a payload for the longest distance?

Question/Problem	What Students Are Doing	What Students Figure Out
How can we make our gliders fly long distances?	Students experiment with glider designs using paper airplanes.	Different forces act on gliders impacting how far the glider can travel.
What happens when we add weight to our gliders?	Students experiment with adding weight to their gliders.	Adding mass to a glider changes the way forces act on the glider, thus changing how far the glider travels.
What materials should we use for our gliders?	Students experiment with different materials to use for their gliders.	Some materials are strong and some materials are light. Gliders should be made out of both strong and light materials.
How can we engineer a glider to carry a payload for long distances?	Students design, build, test, and revise their gliders.	Engineering is an iterative process that builds on core science ideas.

Spy Gliders

Day 1: Define the Problem—Criteria and Constraints

Grade Level	Middle School
Lesson Length	One 50-minute session

Lesson Overview

The module begins with this introductory lesson where students are introduced to the design problem. Students learn about unmanned aerial vehicles (UAVs) and decide on a purpose for their designed systems. Students consider the criteria and constraints for the design problem.

Connecting to the Next Generation Science Standards

In this lesson, students make progress toward developing understanding across the following three dimensions:

- **Science and Engineering Practices:** Asking Questions and Defining Problems
- **Disciplinary Core Ideas:** ETS1.A Defining and Delimiting Engineering Problems
- **Crosscutting Concepts:** Influence of Engineering, Technology, and Science on Society and the Natural World

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

Performance Expectations		
This lesson contributes toward building understanding of the following *engineering* performance expectations: MS-ETS1-1. *<u>Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution</u>*, taking into account relevant scientific principles and *<u>potential impacts on people</u>* and the natural environment that may limit possible solutions.		
Specific Connections to Classroom Activity In this lesson, students are introduced to the design challenge of building unmanned aerial vehicles. They work to define the design challenge by articulating criteria and constraints of the design problem. Later, students use these criteria and constraints to gage their success.		
Dimension	**NGSS Element**	**Connections to Classroom Activity**
Science and Engineering Practices	**Asking Questions and Defining Problems** • *<u>Define a design problem that can be solved through the development of an object, tool, process, or system and includes multiple criteria and constraints,</u>* including scientific knowledge that may limit possible solutions.	Students are given an overarching design problem of engineering a UAV. Students determine a purpose for their UAV (reconnaissance, delivery, and so forth) and define criteria and constraints according to the identified purpose.

Disciplinary Core Ideas	**ETS1.A: Defining and Delimiting Engineering Problems** • *The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful.* Specification of constraints includes consideration of scientific principles and other relevant knowledge likely to limit possible solutions.	Students consider the idea that defining criteria and constraints for their design problem will help measure the success of the design solution.
Crosscutting Concepts	**Influence of Engineering, Technology, and Science on Society and the Natural World** • *The use of technologies and limitations on their use are driven by individual and societal needs, desires, and values*; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions.	When students brainstorm the purpose for their UAV, they consider the needs of individuals and society. Ultimately, students must defend their design decisions based on societal needs. Students also consider societal needs as they develop criteria and constraints for their design solutions.

Basic Teacher Preparation

Students need to be organized into design teams of 3 or 4. They work in their teams throughout this module. Establish the working teams before beginning the first lesson.

This lesson sets the stage for much of the exploration and concept discussion that occurs later in the module. Preview the videos to ensure your audio-visual solution supports the media.

Ensure you have enough copies of the Spy Gliders Student Handbook for all students in your class. Review the Spy Gliders Student Handbook ahead of time so you can address any questions students might have. All documents used on Day 1 are on pages 1 through 3 in the Spy Gliders Student Handbook.

Helpful Tip

Consider giving students a "stamp" of completion each day as they work through the lessons in their handbooks.

The documents used in this lesson are:

- Engineering Design Process Graphic (page 1)
- 1.1: Define the Problem (page 2)
- 1.2: Criteria and Constraints (page 3)

Required Preparation	Links/Additional Information
❑ Download, print, and photocopy the Spy Gliders Student Handbook	Refer to the Materials List below
❑ Review all videos and resources in the Suggested Teacher Resources	Refer to the Suggested Teacher Resources at the end of this lesson

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Spy Gliders Student Handbook	Download, print, and copy for students. Bind all handouts into a Spy Gliders Handbook for students.	1 per student	[Resource Link]
Access to computers or hard copy handouts of UAV ideas (Cool Uses for Drones and The UAV)	Download and print or gain access to computers for student use.	1 per team	See Suggested Teacher Resources

Day 1: Define the Problem—Criteria and Constraints

Introduction (10 minutes)

Introduce the module by asking students what they already know about unmanned aerial vehicles (UAVs). Students may be more familiar with the term drone.

> **Video Link**
>
> - Amazon Prime Drones [Web Link]

Lead a short class discussion about the use of drones locally and globally. For instance, students may be interested to know that Amazon Prime plans to use drones to deliver packages. Show students one of the videos about using drones from Amazon Prime website.

Tell students that UAV's are air vehicles that lack onboard passengers and crew. They can be autonomous drones or remotely piloted vehicles. Many civilian uses exist, including, but not limited to aerial surveying of crops, search and rescue operations, counting wildlife, delivering medical supplies to remote or otherwise inaccessible regions, and surveillance. The military also has many uses for UAVs. A UAV can be used to provide battlefield intelligence, attack capability for high-risk missions, or target and decoy.

To help students better understand UAVs, show the Flite Test—What Is a Drone? Video. Consider previewing the video and selecting several relevant clips rather than showing the entire video.

> **Video Link**
>
> - Flite Test—What Is a Drone? [YouTube Link]

Recently, there has been a greater need to develop UAVs for military and civilian needs. Specifically, there is a need to develop UAVs that can carry a payload. Introduce students to the engineering design problem for the module, *How can we engineer a glider that can carry a payload for the longest distance?* Have students write the engineering design problem on 1.1: Define the Problem on page 2 in the Spy Gliders Student Handbook.

Design Work: Decide on a Purpose (10 minutes)

Tell students to determine a purpose for their UAV. The only requirement is that the UAV must carry a payload. Have students explore several resources about the uses for drones.

Cool Uses for Drones offers ideas for civilian use, and The UAV offers ideas for military uses.

> **Video Link**
>
> - Cool Uses for Drones [Web Link]
> - The UAV [Web Link]

Students may also decide to explore additional websites or create their own ideas.

After students decide on the purpose for their UAVs, have them share their justifications with the class. Record each team's purpose and justification on the board.

NGSS Key Moment

As students brainstorm purposes for their UAVs, they should think about individual and societal demands, and how the demands influence their design decisions. Doing so emphasizes the crosscutting concept—Influence of Engineering, Technology, and Science on Society and the Natural World.

Extension

Consider creating a master list of uses for drones to support students who may not be familiar with drones. Potential uses include:

Civilian
- Mail/package delivery
- Sports photography
- Highway monitoring
- Wildlife research
- Disaster relief

Military
- Target and decoy
- Reconnaissance
- Combat
- Research and development

Whole Group Discussion: Engineering Design Process (5 minutes)

Tell students that over the next several days, their task is to use the engineering design process to solve the design problem. To introduce students to the engineering design process, show MIT's Introduction to the Engineering Design Process video and then review the Engineering Design Process graphic, shown on page 1 in the Spy Gliders Student Handbook and Appendix A in the Spy Gliders Teacher Handbook.

Video Link

- MIT's Introduction to the Engineering Design Process video [YouTube Link]

Consider relating the engineering design process to a simple problem with which students are familiar. For instance, use a simple math problem, a riddle, or an everyday problem, such as deciding on what to eat for dinner. Relating the engineering design process to a simple, everyday problem helps students start thinking about the problem solving and redesign process.

NGSS Key Moment

Engineers often refer to the **engineering design process** when they discuss their work. In the NGSS, the Science and Engineering Practices are used in place of the engineering design process. Students should understand that the engineering design process is not linear in practice. Rather, engineers engage in all of the steps, often jumping between steps. Students may want to think of the engineering design process as a web of practices.

Whole Group Discussion: Define Criteria and Constraints (5 minutes)

If students are not familiar with the terms criteria and constraints, lead a class discussion to develop a consensus definition for the terms. Tell students that as they start an engineering design project, they need to determine the criteria and constraints that the design solution must meet. Ask students to try to define criteria and constraints. Ask them to share some examples.

Design Work: Our Questions (10 minutes)

Have students turn to 1.1: Define the Problem on page 2 in the Spy Gliders Student Handbook. Students should have already recorded the Engineering Design Challenge, *How can we engineer a glider that can carry a payload for the longest distance?*

- For several minutes, have students think to themselves and jot down a few questions that will help set up the criteria and constraints for this engineering design challenge.
- Then, for several minutes, have students talk with their partners as a pair to come up with the best set of questions.
- For the last several minutes, invite students to share their questions with the class to develop the criteria and constraints.

Design Work: Criteria and Constraints (10 minutes)

Tell students that when they engage in an engineering design problem, they must have a way to measure success. Engineers often measure success by assessing how successfully they have met the criteria and constraints of a design problem. Tell students to brainstorm what a successful solution will entail.

NGSS Key Moment

As students brainstorm criteria and constraints, they should take into account individual and societal demands and the impact on society and the natural world.

Have students complete 1.2: Criteria and Constraints on page 3 in the Spy Gliders Student Handbook. Have students discuss with a partner and then add additional criteria and constraints. Invite students to share their ideas with the class.

Assessment

Several opportunities for formative assessment exist in this lesson:

- Spy Gliders Student Handbook entries can be used to monitor student progress during the module. For this lesson, focus specifically on 1.1: Define the Problem and 1.2: Criteria and Constraints.
- Whole class share-outs and discussions allows for formative assessment of student ideas and building content knowledge.
- When students are meeting in small groups, spend time with each group, listening in on their process and providing support as needed.

Use the identified assessment opportunities to monitor student progress on disciplinary core ideas, science and engineering practices, and crosscutting concepts. Provide appropriate supports or extensions when necessary.

Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

Research and share companies in the region that engage, use, or develop UAVs. Consider inviting an employee of a company using UAVs to talk with the class.

Suggested Teacher Resources

Engineering Design Process	Spy Gliders Teacher Handbook, Appendix A
Meeting the Needs of All Learners	Spy Gliders Teacher Handbook, Appendix B
Spy Glider Student Handbook	[Resource Link]
Amazon Prime Drones (video)	[Web Link]
MIT—Engineering Design Process (video)	[YouTube Link]
Flite Test—What Is a Drone? (video)	[YouTube Link]
Cool Uses for Drones	[Web Link]
The UAV	[Web Link]

Spy Gliders

Day 2: How Planes Fly

Grade Level	Middle School
Lesson Length	One 50-minute session

Lesson Overview

In this lesson, students investigate the forces involved in flight. Students visit four different stations, each featuring a different investigation designed to help students make sense of the forces involved in flight. Students create a series of models to explain their developing ideas about flight.

After developing initial ideas about the forces involved in flight, students design prototype airplanes to test their ideas. Students investigate the features of gliders to learn what makes them stable for long distances. They test paper planes to see which ones perform the best and look for design similarities among the successful tests. Students then use the four forces of flight—lift, drag, thrust, and gravity—to better explain their test flight observations. This lesson reinforces essential pieces of the engineering design process, especially testing, making observations, and recording data.

Connecting to the Next Generation Science Standards

In this lesson, students make progress toward developing understanding across the following three dimensions:

- Science and Engineering Practices: Developing and Using Models, Analyzing and Interpreting Data
- Disciplinary Core Ideas: ETS1.B Developing Possible Solutions, ETS1.C Optimizing the Design Solution, PS2.A Force and Motion
- Crosscutting Concepts: Cause and Effect

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

Performance Expectations
This lesson contributes toward building understanding of the following *engineering* performance expectations: MS-ETS1-3. *Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.* MS-ETS1-4. *Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.* **This lesson contributes toward building understanding of the following *physical science* performance expectations:**

MS-PS2-2. Plan an investigation to provide evidence that *the change in an object's motion depends on the sum of the forces on the object* and the mass of the object.

Specific Connections to Classroom Activity

In this lesson, students develop an initial understanding of the forces involved in flight. Using their knowledge of the forces involved in flight, students create and test a prototype glider using paper airplanes. They collect and compare data from the tests and revise their gliders accordingly. As students experiment with glider designs, they consider the ways that thrust, lift, gravity, and drag apply force on the airplane. This sets students up to begin thinking about what might happen if they add weight to their glider.

Dimension	NGSS Element	Connections to Classroom Activity
Science and Engineering Practices	**Developing and Using Models** • *Develop a model to predict and/or describe phenomena.* • *Develop a model to generate data to test ideas about designed systems,* including those representing inputs and outputs. **Analyzing and Interpreting Data** • *Analyze and interpret data to determine similarities and differences in findings.*	In this lesson, students create a series of models to describe the phenomenon of flight. In addition, students use a paper airplane model to test glider designs. Students modify their models to optimize performance. Students test a variety of glider designs to determine the best characteristics of each design. During the tests, students collect qualitative and quantitative data and compare their findings.
Disciplinary Core Ideas	**ETS1.B: Developing Possible Solutions** • *A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.* • *Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.* • *Models of all kinds are important for testing solutions.* **ETS1.C: Optimizing the Design Solution** • *Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.* • *The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.* **PS2.A: Force and Motion** • *The motion of an object is determined by the sum of the forces acting on it*; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in	Students develop and test several glider designs. Students work to optimize their designs based on data from their tests. As students test glider designs, they should realize that some gliders do not perform well. In later lessons, students should find that these same designs work well when weight is added. This lesson sets students up for this understanding. In previous lessons (not included in this module), students should have already developed the idea that the motion of an object is determined by the sum of the forces acting on it. In this lesson, students develop an idea of the forces acting on an airplane to keep it in the air.

	motion. For any given object, a larger force causes a larger change in motion.	
Crosscutting Concepts	**Cause and Effect** • *Cause and effect relationships may be used to predict phenomena in natural or designed systems.*	Students recognize that changes to their airplanes affect the distances they travel.

Basic Teacher Preparation

Students should work in their design teams for this lesson. Prior to the lesson, set up four stations for student investigations. If possible, create the paper helicopters prior to class to save time. Directions for folding the helicopters can be found at Paper Helicopters.

Web Resources

- Paper Helicopters [Web Link]
- Talk Science Primer [Web Link]

Four Stations

1. Station #1: Tent with a Straw—Enough straws for each student, 5 or 6 pieces of 20x13cm paper
2. Station #2: Ball and Straw—Enough straws for each student, 5 or 6 ping pong balls
3. Station #3: Paper Paper—6 to 8 pieces of notebook paper
4. Station #4: Helicopters—5 or 6 premade paper helicopters

Preview the required videos and have plenty of paper available for the paper airplanes. Review the Talk Science Primer, to help you prepare to lead the whole class discussion.

Refer to the Spy Gliders Student Handbook ahead of time so you can address any questions students might have. All documents used on Day 2 are on pages 4 through 10 in the Spy Gliders Student Handbook. The documents used in this lesson are:

- 2.1: How Planes Fly: Initial Model (page 4)
- 2.2: How Objects Fly: Stations (pages 5 and 6)
- 2.3: How Planes Fly: Revised Model (page 7)
- 2.4: How to Make an Airplane Fly (page 8)
- 2.5: Design Strengths and Failure points (page 9)
- 2.6: How Planes Fly: Final Model (page 10)

Required Preparation	Links/Additional Information
❑ Gather or purchase all necessary materials	Refer to the Materials List below
❑ Set up the stations for student investigations	Refer to the Materials List below and the Four Stations list above
❑ Review all videos and resources in the Suggested Teacher Resources	Refer to the Suggested Teacher Resources at the end of this lesson

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Standard 8.5” x 11” computer paper		5–10 pieces per student	Available in most schools
Standard 12” ruler		1 per student	Available in most schools
Straws	Provide each student with one straw to use during the stations activity	1 per student	Available at most stores
20 cm x13 cm computer paper	Cut computer paper to meet the size requirements	5 or 6 pieces	Available in most schools
Ping pong balls		5 or 6 balls	Available in most stores
Notebook paper		6–8 pieces	Available in most schools
Paper helicopters	Make the helicopters prior to student investigations	5 or 6 helicopters	[Web Link]

Day 2: How Planes Fly

Introduction (5 minutes)

Begin the lesson by leading a short class discussion on flight. Ask students to share what they already know about what makes things fly. At this point in the lesson, accept all responses.

Pose the question, *How can an airplane fly?* Generate interest in the question by emphasizing the weight and size of the airplane. Students might be perplexed about why a massive airplane can fly through the air.

Instruct students to develop an initial model that shows how airplanes are able to fly on 2.1: How Planes Fly: Initial Model on page 4 in the Spy Gliders Student Handbook.

Students should record their ideas in words, pictures, and diagrams. Students should attempt to articulate the forces involved in flight. Again, at this point in the lesson, accept all ideas.

NGSS Key Moment

Use students' draft models to gage their understanding of the forces involved in flight. Provide appropriate supports or extensions throughout the lesson according to student performance on this task.

Investigation: How Objects Fly (15 minutes)

After creating their initial models, students might have questions about how airplanes fly. Students engage in a series of investigations to better understand flight. Each investigation is designed to help students develop initial ideas about the forces involved in flight.

Introduce students to 2.2: Stations: How Objects Fly: Stations on pages 5 and 6 **in the** Spy Gliders Student Handbook. In this activity, students work in teams to complete four stations. At each station, students engage in an investigation designed to help them better understand the science of flight. The four stations, materials, and associated questions are listed below. Directions for folding the helicopters can be found at [Paper Helicopters].

Video Link

- Paper Helicopters [Web Link]

Station #1: Tent with a Straw

Materials—Enough straws for each student, 5 or 6 pieces of 20 cm x 13 cm paper

1. Fold a 20 cm by 13 cm piece of paper in half to make a tent.
2. Place the paper tent on the desk.
3. Using a straw, blow under the tent and observe what happens.
4. Blow harder and observe what happens.
5. Try blowing hard against the side of the tent and observe what happens.

- What happened?
- How can you explain this?

Station #2: Ball and Straw

Materials—Enough straws for each student, 5 or 6 ping pong balls

1. Bend a flexible straw so the short end is pointing up.
2. Hold a ping pong ball over the opening of the straw and blow.
3. Let go of the ball and observe what happens.
4. What happens if you tilt the straw?

- What happened?
- How can you explain this?

Station #3: Paper Paper

Materials—6 to 8 pieces of notebook paper

1. Hold two pieces of notebook paper in front of you about 5 cm apart.
2. Blow hard between the papers and observe what happens.

- What happened?
- How can you explain this?

Station #4: Paper Helicopters

Materials—5 or 6 premade paper helicopters

1. Obtain a premade paper helicopter.
2. Drop the helicopter from a height and notice how it falls.
3. Change the shape/direction of the blades.
4. Does this change the direction or speed of the rotation?
5. What is making this rotate?

- What happened?
- How can you explain this?

As students rotate through the stations, monitor team work. Ask students probing questions to help them think about the forces involved in flight. Students should complete 2.2: How Objects Fly: Stations on pages 5 and 6 in the Spy Gliders Student Handbook.

After conducting the investigations, have students develop a revised model for how airplanes fly on 2.3: How Planes Fly: Revised Model on page 7 in the Spy Gliders Student Handbook. Students should incorporate evidence from their investigations in the revised model.

Design Work: Designing Prototype Paper Airplanes (10 minutes)

Now that students have developed initial ideas about flight, they test their ideas by designing prototype paper airplanes. Students work to determine the characteristics of airplaine design that help planes travel long distances. To do so, students develop model airplanes and test which characteristics impact distance traveled.

Students begin this process by brainstorming potential designs. Distribute paper and rulers to students. Instruct them to turn to 2.4: How to Make an Airplane Fly on page 8 in the Spy Gliders Student Handbook. Working individually, students sketch a paper airplane that they believe will travel the greatest distance, with a minimum expectation of at least 5 feet. Students should include labels and measurements in their sketches. They should also provide reasons as to why certain design features might help their planes fly farther. Students should draw on the station investigations to justify their design decisions.

After students complete their designs, have them use the provided paper to carefully construct their paper airplanes based on their blueprints. They should also write down a prediction about how far or how well their planes will fly.

NGSS Key Moment

Use students' draft designs and justifications to gage their progress on MS-PS2-2. Provide appropriate supports or extensions throughout the lesson according to student performance on this task.

Extension

Consider providing students with a starting point for their airplane designs, such as providing students with a link to FoldnFly or distribute a printout of example airplanes.

Design Work: Testing Prototype Paper Airplanes (10 minutes)

Have students work with a partner to test their gliders. Encourage them to throw the plane consistently so they can observe how different designs affect flight. They should also sketch and note design strengths as well as failure points or weaknesses for at least two of the gliders on 2.5: Design Strengths and Failure Points on page 9 in the Spy Gliders Student Handbook.

After testing their airplane, have students develop a final model for how airplanes fly. Students should record their model on 2.6: How Planes Fly: Final Model on page 10 in the Spy Gliders Student Handbook. Emphasize that students should incorporate evidence from the stations activity and from the prototype paper airplane activity.

NGSS Key Moment

Have students record quantitative and qualitative data to measure how well the airplane flew. Students can measure distance traveled, stability, or direction traveled. Students should incorporate these observations in the "Failure Points" boxes in the student handbook.

Whole Group Discussion: How do planes fly? (10 minutes)

Engage students in a whole group discussion to try to come to consensus about how planes fly. Focus specifically on the forces involved in flight. The goal of the discussion should be to generate a class model for flight that shows the forces involved in flight.

Students may discuss the concepts of lift, thrust, gravity, and drag, although they may not necessarily use the appropriate vocabulary to discuss the concepts. Once students have developed the science ideas behind lift, thrust, gravity, and drag, introduce students to the appropriate vocabulary by showing them the picture below.

NGSS Key Moment

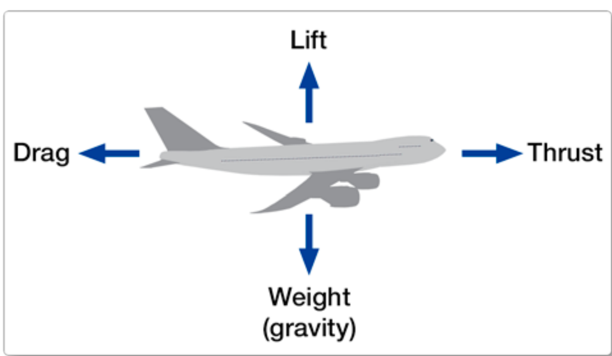
Whole group discussions, particularly consensus discussions, can be an effective way to engage students in the science practices of argumentation and explanation. Leading whole group discussions requires proper preparation. Refer to the Talk Science Primer for useful strategies.

For more information, access NASA: Four Forces on an Airplane, and as a class, review thrust, weight, lift, and drag.

To conclude the discussion, show the Aerodynamics of Flight, Science of Flight—Part 1, or PBS—Challenge of Flight video to students. For additional information on the forces of flight and paper airplanes, view BrainPop Flight Adventures, The Thrill of Flight, Fold N Fly, Fun Paper Airplanes, and Michael Despezio Inspired Planes.

Web Resources

- NASA: Four Forces on an Airplane [Web Link]



Video Links

- Aerodynamics of Flight [YouTube Link]
- Science of Flight—Part 1 [YouTube Link]
- PBS—Challenge of Flight [Web Link]
- BrainPop Flight Adventures [Web Link]
- The Thrill of Flight [Web Link]
- Fold N Fly [Web Link]
- Fun Paper Airplanes [Web Link]
- Michael Despezio Inspired Planes [Web Link]

Extension

To further support or extend student understanding of the forces involved in flight, consider purchasing small polystyrene gliders (commonly found in the party favor sections of stores) and long bamboo skewers (found in most grocery stores). Carefully insert the skewers horizontally, just under the wings to show the horizontal axis. Do the same through the fuselage at the center of gravity to form a vertical axis. For a horizontal axis from front to back (nose to tail), shorten two skewers and insert the pointed ends through the nose and tail. Make one plane for each team. Give students time to explore and visualize thrust, lift, gravity, and drag. Also consider introducing the following motions of flight: *pitch*, *roll*, and *yaw*.

Assessment

Several opportunities for formative assessment exist in this lesson:

- Spy Gliders Student Handbook entries can be used to monitor student progress throughout the module. For this lesson, pay particular attention to the series of models explaining how planes fly (2.1: How Planes Fly: Initial Model, 2.3: How Planes Fly: Revised Model, and 2.6: How Planes Fly: Final Model). Also consider using student design ideas (2.4: How to Make an Airplane Fly and 2.5: Design Strengths and Failure Points) to gage student progress in understanding and engaging in the engineering design process.
- Whole class share-outs and discussions allows for formative assessment of student ideas and building content knowledge.
- When students are meeting in their teams, spend time with each team, listening in on their process and providing support as needed.

Use the identified assessment opportunities to monitor student progress on disciplinary core ideas, science and engineering practices, and crosscutting concepts. Provide appropriate supports or extensions when necessary.

Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

If any student's parents, guardians, family members, or relatives work as aerospace engineers, materials engineers, pilots, or aviation mechanics, consider inviting them to visit the classroom as volunteers or to share their work experiences.

Suggested Teacher Resources

Meeting the Needs of All Learners	Spy Gliders Teacher Handbook, Appendix B
Talk Science Primer	[Web Link]
The Aerodynamics of Flight video	[YouTube Link]
The Science of Flight—Part 1 video	[YouTube Link]
NASA Four Forces on an Airplane	[Web Link]
PBS—Challenge of Flight	[Web Link]
Directions for Paper Helicopters	[Web Link]
BrainPop Flight Adventures	[Web Link]
The Thrill of Flight	[Web Link]
Fold N Fly	[Web Link]
Fun Paper Airplanes:	[Web Link]
Michael Despezio Inspired Planes	[Web Link]

Spy Gliders

Day 3: How Weight Affects Flight

Grade Level	Middle School
Lesson Length	One 50-minute session

Lesson Overview

In this lesson, students dig into their roles as engineers by working through the engineering design process to solve a challenge. This challenge involves modifying a polystyrene airplane to travel a certain distance while carrying a certain number of paper clips. Adding a payload to the glider, without affecting its ability to fly successfully, is a major component of the capstone engineering design challenge.

Connecting to the Next Generation Science Standards

In this lesson, students make progress toward developing understanding across the following three dimensions:

- Science and Engineering Practices: Planning and Carrying Out Investigations, Analyzing and Interpreting Data, Constructing Explanations and Designing Solutions
- Disciplinary Core Ideas: ETS1.B Developing Possible Solutions, ETS1.C Optimizing the Design Solution, PS2.A Force and Motion
- Crosscutting Concepts: Cause and Effect

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

Performance Expectations
This lesson contributes toward building understanding of the following *engineering* performance expectations: MS-ETS1-3. *Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.* MS-ETS1-4. *Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.* **This lesson contributes toward building understanding of the following *physical science* performance expectations:** MS-PS2-2. *Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.*
Specific Connections to Classroom Activity In this lesson, students test what happens when they add weight to their gliders. Students experiment with ways to attach the weight to the glider to maximize the distance traveled. They collect data from their tests and make modifications to try to improve their gliders. At the end of the lesson, students engage in a discussion to try to explain how the weight impacted their gliders.

Dimension	NGSS Element	Connections to Classroom Activity
Science and Engineering Practices	**Planning and Carrying Out Investigations** • *Plan an investigation individually and collaboratively* and in the design identify independent and dependent variables and *controls, what tools are needed to do the gathering, and how many data are needed to support a claim.* **Analyzing and Interpreting Data** • *Analyze and interpret data to determine similarities and differences in findings.* **Constructing Explanations and Designing Solutions** • *Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process, or system.*	Students plan a strategy to systematically test their gliders after they add weight. Students carry out their systematic process. Students do not identify the variables outright, but they do identify the controls and the data to collect. After carrying out their tests, students use the data they collect to make changes to their gliders. When students share their results with the class, they compare and contrast findings. Students work with the ideas of forces and motion to design a glider capable of carrying a payload.
Disciplinary Core Ideas	**ETS1.B: Developing Possible Solutions** • *A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.* • *Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.* • *Models of all kinds are important for testing solutions.* **ETS1.C: Optimizing the Design Solution** • *Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process-that is, some of those characteristics may be incorporated into the new design.* • *The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.* **PS2.A: Force and Motion** • *The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.*	Students design a systematic process to test, modify, and retest their design solutions based on the results of the trials. Students consider combining characteristics of multiple solutions to create a solution that is better than its predecessors. Throughout the module, students conduct a variety of tests under different conditions. In the previous lesson, students tested glider designs. In this lesson, students test payload. In the final design, students incorporate aspects of all designs. In addition, students iteratively test their glider designs for carrying a payload. In this lesson, students experiment with adding mass to the glider. Students realize that when they add mass, more force is needed to help the glider travel the same distance. In addition, the placement of the mass makes a difference for glider performance.
Crosscutting Concepts	**Cause and Effect**	Through their investigations, students realize that when they move the mass, the glider flies differently.

	• Cause and effect relationships may be used to predict phenomena in natural or designed systems.	

Basic Teacher Preparation

Ensure that all of the supplies are laid out and students have access to the proper measuring equipment and materials.

Review the Talk Science Primer, to help you prepare to lead the whole class discussion.

Refer to the Spy Gliders Student Handbook ahead of time so you can address any questions students might have. All documents used on Day 3 are on pages 11 through 14 in the Spy Glider Student Handbook. The documents used in this lesson are:

- 3.1: How Weight Affects Flight (page 11)
- 3.2: How Weight Affects Flight: Payloads (page 12)
- 3.3: How Weight Affects Flight: Systematic Process (page 13)
- 3.4: How Weight Affects Flight: Work Space (page 14)

Required Preparation	Links/Additional Information
❑ Gather and set out all necessary materials	Refer to the Materials List below
❑ Review all videos and resources in the Suggested Teacher Resources	Refer to the Suggested Teacher Resources at the end of this lesson

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Small action camera	An action camera is an engaging way for students to capture aerial footage during the final engineering design challenge. If it is cost prohibitive, a battery would be a suitable alternative.	1 per class	Camera [Web Link]
Foam (polystyrene) gliders	The longer the wing span, the better.	1 per team	Gliders [Web Link]
Metal washers		10 per team	Washers [Web Link]
Paper clips and washers	Paper clips can be used as fasteners or weights if you should use smaller gliders.	1 box per class	Any office supply store
Duct tape		1 roll per class	Any hardware store

Day 3: How Weight Affects Flight

Introduction (10 minutes)

Instruct students to sit in their prearranged teams, and have them read 3.1: How Weight Affects Flight on page 11 in the Spy Gliders Student Handbook. On this page, students are introduced to team roles. The team roles include: Project Director, Recorder, Material Manager, and Safety Direct. For teams of three, two roles can be combined. After reading about the roles, have students work together to choose a role for each member of the team. Students keep their roles for the remainder of this module.

Whole Group Discussion: Adding a Payload (5 minutes)

Tell students that the next part of their design problem is to make sure that their glider can carry a payload. Remind students of the purposes for their gliders. Their design task at this stage is to adapt a glider to travel a certain distance while carrying a certain number of washers. Point out all of the materials and demonstrate how to assemble the glider. Point out that the polystyrene glider is fragile.

Design Work: Team Planning (10 minutes)

Instruct students to review the design task on 3.2: How Weight Affects Flight: Payloads on page 12 in the Spy Gliders Student Handbook. Inform the class of the distance the gliders should fly and the number of washers that should be attached. Have students record the goal numbers. Then, have students work together in teams to sketch where and how to attach the washers to their gliders.

> **Helpful Tip**
>
> Determine the level of difficulty, and tell students the distance the glider should fly and the number of washers it should carry. If desired, consider having the class work together to determine these goals.

Students should defend their decisions by sketching force diagrams that include thrust, lift, gravity, and drag. Students should add the additional mass to the diagram and adjust their diagram as they see fit.

Investigation: Adding Weight (15 minutes)

Students work in their teams to complete 3.2: How Weight Affects Flight: Payload (page 12) and 3.3: How Weight Affects Flight: Systematic Process (page 13) in the Spy Gliders Student Handbook. Be sure they use the included guiding questions to help them determine which solution is the best option.

Students should then carry out their investigation plans. Students should use 3.4: How Weight Affects Flight: Work Space on page 14 in the Spy Gliders Student Handbook to record notes during testing.

NGSS Key Moment

Planning their own systematic testing process helps students make progress on Planning and Carrying out Investigations.

Whole Group Discussion: How Adding Weight Changes the Glider (10 minutes)

At the end of testing, have students reflect on the following prompt, *How did the sketch of the glider and the placement of the payload change over the course of testing?*

Engage students in a whole group discussion about how the glider changed. After students have started to observe some trends in how the glider changed, ask students why they think they needed to make the modifications to the glider. Guide students to the idea that when the mass changes, other forces involved must change so the glider can travel the same distance (as it might without the mass). At this point in the discussion, students should understand that mass makes a difference. Later, students model how mass impacts the forces involved in helping an airplane fly.

NGSS Key Moment

Thinking about how their gliders changed guides students to think about how adding mass caused the change.

Assessment

Several opportunities for formative assessment exist in this lesson:

- Spy Gliders Student Handbook entries can be used to monitor student progress during the module. For this lesson, focus specifically on 3.3: How Weight Affects Flight: Systematic Process on page 13 in the Spy Gliders Student Handbook to gage student progress on Planning and Carrying Out Investigations.
- Whole class share-outs and discussions allows for formative assessment of student ideas and building content knowledge.
- When students are meeting in their teams, spend time with each team, listening in on their process and providing support as needed.

Use the identified assessment opportunities to monitor student progress on disciplinary core ideas, science and engineering practices, and crosscutting concepts. Provide appropriate supports or extensions when necessary.

Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

If any student's parents, guardians, family members, or relatives work as aerospace engineers, materials engineers, pilots, or aviation mechanics, consider inviting them, or other local professionals in these relevant fields, to visit the classroom as volunteers or to share their work experiences.

Suggested Teacher Resources

Meeting the Needs of All Learners	Spy Gliders Teacher Guide, Appendix B
Talk Science Primer	[Web Link]

Spy Gliders

Days 4 and 5: Spy Glider Materials

Grade Level	Middle School
Lesson Length	Two 50-minute sessions

Lesson Overview

On Days 4 and 5, student teams explore what materials to use based on strength and weight. Part of the time involves brainstorming and researching materials used on other planes and gliders. The rest of the time is dedicated to hands-on material testing. Finally, students use an argument scale (see Suggested Teacher Resources) to reach consensus on the best materials to use.

Connecting to the Next Generation Science Standards

In this lesson, students make progress toward developing understanding across the following three dimensions:

- Science and Engineering Practices: Planning and Carrying Out Investigations, Analyzing and Interpreting Data, Constructing Explanations and Designing Solutions
- Disciplinary Core Ideas: ETS1.B Developing Possible Solutions
- Crosscutting Concepts: Cause and Effect

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

Performance Expectations		
This lesson contributes toward building understanding of the following *engineering* performance expectations: MS-ETS1-3. *Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each* that can be combined into a new solution to better meet the criteria for success.		
Specific Connections to Classroom Activity In this lesson, students develop a strategy to test various materials for strength and weight. Students gather data for different materials and compare results across materials. Based on their findings, students select materials to use for their gliders.		
Dimension	**NGSS Element**	**Connections to Classroom Activity**
Science and Engineering Practices	**Planning and Carrying Out Investigations** • *Plan an investigation individually and collaboratively* and, in the design, identify independent and dependent variables *and controls, what tools are needed to do the gathering, and how many data are needed to support a claim.* **Analyzing and Interpreting Data**	Students design an investigation to determine which materials are strongest and lightest. Students carry out the investigation to determine which materials to use for their gliders. Students collect and analyze data to determine which materials to use for their gliders.

	• *Analyze and interpret data to determine similarities and differences in findings.* **Constructing Explanations and Designing Solutions** • *Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process, or system.*	Students develop a final explanation for their material selection. The explanation is based on evidence and takes into consideration possible design alternatives.
Disciplinary Core Ideas	**ETS1.B: Developing Possible Solutions** • *A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.* **ETS1.C: Optimizing the Design Solution** • *Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process-that is, some of those characteristics may be incorporated into the new design.*	Students test multiple materials and determine which materials to use for their gliders. Students test materials for both weight (of the material) and strength. Students find that although one material might perform well on the weight test, it might not necessarily perform well on the strength test. Ultimately, students make a design decision that balances both weight and strength.
Crosscutting Concepts	**Cause and Effect** • *Cause and effect relationships may be used to predict phenomena in natural or designed systems.*	Students work with the idea that different amounts of weight cause different materials to break.

Basic Teacher Preparation

Gather and set out all necessary materials for Days 4 and 5. Review all resources, including the identified videos and How to Use a Spring Scale presentation, and ensure they can be shown for the class.

Consider ways students might be able to use the provided items to test the various construction materials. Refer to the Spy Gliders Student Handbook ahead of time so you can address any questions students might have. All documents used on Days 4 and 5 are on pages 15 through 18 in the Spy Glider Student Handbook. The documents used in this lesson are:

- 4.1: Materials Warm Up (page 15)
- 4.2: Controlled Investigation: Materials Testing (page 16)
- 5.1: Materials Testing Data Table (page 17)
- 5.2: Materials Debrief (page 18)

Web Resources

- How to Use a Spring Scale presentation [Web Link]

Required Preparation	Links/Additional Information
❑ Gather and set out all necessary materials	Refer to the Materials List below
❑ Preview all identified videos and the Spring Scale Presentation	

❑ Review all videos and resources in the Suggested Teacher Resources	Refer to the Suggested Teacher Resources at the end of the lesson

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Triple beam balance		1 per class	Available in most schools
Small action camera	An action camera is an engaging way for students to capture aerial footage during the final engineering design challenge. If it is cost prohibitive, a battery would be a suitable alternative.	1 per class	Already used on Day 3
Foam (polystyrene) gliders	The longer the wing span, the better.	1 per team	Already used On Day 3
Metal washers		10 per team	Already used on Day 3
Paper clips	These can be used as fasteners or weights if smaller gliders are used.	1 box per class	Already used on Day 3
Duct tape		1 roll per class	Already used on Day 3
Hot glue gun		1 for every 2 teams	Hot glue gun [Web Link]
Balsa wood		1 per team	Balsa wood [Web Link]
Foam board		1 per team	Foam board [Web Link]
Scrap cardboard		1 large box per team	From school cafeterias or home
Very fine sanding blocks		1 per team	Sanding blocks [Web Link]
S hooks		1 per team	S hooks [Web Link]
Fishing line, twine, or yarn		1 package	Local store or home

Day 4: Spy Glider Materials

Introduction (10 minutes)

Instruct students to complete the writing exercise on 4.1: Materials Warm Up on page 15 in the Spy Gliders Student Handbook. In this writing exercise, students think about the properties of materials used to make a successful glider. Students also brainstorm the materials that they would like to use to create their final gliders.

Have students focus their writing on the importance of material selection in glider construction. After students finish writing, engage in a whole class discussion. Have students share their ideas about the materials needed for their final gliders.

Tell students that their next step in the design process is to determine which materials to use for their gliders.

Mini-Lesson: Preparing for the Materials Investigation (15 minutes)

Show and discuss the Boeing Wing Failure Test video. Then show and discuss the Mythbusters video, which shows the use of a force gauge. Discuss how the videos relate to the challenge of selecting materials for use in the gliders.

Use How to Use a Spring Scale to lead a class discussion about the appropriate use of spring scales. Discuss how students could use a spring scale to measure the strength of materials.

Video Links

- Boeing Wing Failure Test [YouTube Link]
- Mythbusters force gauge [YouTube Link]

Web Resources

- How to Use a Spring Scale presentation [Web Link]

Design Work: Materials Hypothesis and Testing Procedures (25 minutes)

Tell students to turn to 4.2: Controlled Investigation: Materials Testing on page 16 in the Spy Gliders Student Handbook. Have them work individually to generate a hypothesis about the various glider construction materials. Then have students collaborate as a team to develop a strength testing procedure. Review and sign off on each team's procedure.

NGSS Key Moment

Designing an investigation to determine the strengths of different materials helps students make progress on the practice of Planning and Carrying Out Investigations.

One basic method of strength testing is to have a rectangular piece of material suspended lengthwise between two desktops. A string is then wrapped down the middle, width-wise, with an S hook suspended from it. Washers or hooked gram stackers are added until the material breaks.

Day 5: Spy Glider Materials

Design Work: Materials Testing (25 minutes)

Inform students that they will strength test at least three construction materials to the point of failure. Instruct them to refer to 5.1: Materials Testing Data Table on page 17 in the Spy Gliders Student Handbook. As students conduct their testing, they must note the specific type of material, mass of the material, and amount of mass that each material can support prior to collapse. They should also note the pros and cons of each material and provide a summary in the Results section.

NGSS Key Moment

Completing the data table helps students make progress on the practice of Analyzing and Interpreting data. Encourage students to carefully interpret data prior to listing the pros and cons of the material.

Design Work: Materials Debrief (25 minutes)

Have students individually reflect on the testing process as they complete the journal activity on 5.2 Materials Debrief on page 18 in the Spy Gliders Student Handbook.

Next, have students work in their teams to come to a consensus about which materials to use to build their gliders. Have students record notes from their team consensus discussions.

Helpful Tip

Consider using one of the argumentation activities to help each group come to a consensus.

NGSS Key Moment

Although the word *argument* is used in the student handbook, students are really developing an explanation for why they believe their material selection is the best option.

Assessment

Several opportunities for formative assessment exist in this lesson:

- Spy Gliders Student Handbook entries can be used to monitor student progress during the module. For this lesson, focus specifically on 4.2: Controlled Investigation: Materials Testing (page 16) and 5.2: Materials Debrief (page 18) to gage student progress on MS-ETS1-3.

- Whole class share-outs and discussions allows for formative assessment of student ideas and building content knowledge.
- When students are meeting in their teams, spend time with each team, listening in on their process and providing support as needed.

Use the identified assessment opportunities to monitor student progress on disciplinary core ideas, science and engineering practices, and crosscutting concepts. Provide appropriate supports or extensions when necessary.

Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

If any student's parents, guardians, family members, or relatives work as aerospace engineers, materials engineers, pilots, or aviation mechanics, consider inviting them, or other local professionals in these fields, to visit the classroom as volunteers or to share their work experiences.

Suggested Teacher Resources

Meeting the Needs of All Learners	Spy Gliders Teacher Handbook, Appendix B
Boeing Wing Failure Test videos	[YouTube Link]
Mythbusters Force Gauge video	[YouTube Link]
How to Use a Spring Scale presentation	[Web Link]
Argumentation Activity	[Web Link]

Spy Gliders

Days 6 through 9: Construction, Testing, and Optimization

Grade Level	Middle School
Lesson Length	Four 50-minute sessions

Lesson Overview

On these planning, building, and testing days, students bring together what they learned about glider shape, payload, and construction materials as they work in teams to create their gliders. The teams start by creating labeled diagrams of their planned gliders. The diagrams should note what features they think will help their gliders meet the challenge's criteria and constraints. Once each team has presented their plan to the teacher and the class, the team can then begin to build. Students should have at least two days to build their gliders and allow for glue to dry.

On Days 8 and 9, students test their model gliders in the field. They begin by making predictions as to which gliders will travel the longest distance at the highest elevation. As the gliders are tested, each student records quantitative data about the distance traveled as well as any qualitative observations.

Connecting to the Next Generation Science Standards

On Days 6 through 9, students demonstrate understanding of the performance expectations and three dimensions developed throughout the entire module. This lesson serves as a performance assessment in which all of the performance expectations and dimensions are addressed in the final presentation. Reference the performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts referenced in the front matter of this module.

Basic Teacher Preparation

Ensure the required supplies are available and organized for the students. Make sure students know the safety precautions that should be taken while working with scissors and/or utility knives to cut the materials. Identify a safe area and establish a clear cadence for throwing the gliders. To ensure testing consistency, think of a way to ensure all teams throw in the same fashion, or identify a designated "thrower" to allow for a more equitable comparison. If possible, build a glider prior to class as a way to prepare to support students throughout the process.

Refer to the Spy Gliders Student Handbook ahead of time so you can address any questions students might have. All documents used on Days 6 through 9 are on pages 19 through 27 in the Spy Gliders Student Handbook. The documents used in this lesson are:

- 6.1: Build Day (page 19)
- 6.2: Conceptual Model (page 20)
- 6.3: Build Day Debrief (page 21)
- 8.1: Test Day (page 22)

- 8.2: Test Day: Data Table (page 23)
- 9.1: Redesign and Retest (page 24)
- 9.2: Redesign and Retest: Data Table II (page 25)
- 9.3: Optimal Design (page 26)
- 9.4: Analysis of Results (page 27)

Required Preparation	Links/Additional Information
❑ Gather and set out all necessary materials	Refer to the Materials List below
❑ Review all videos and resources in the Suggested Teacher Resources	Refer to the Suggested Teacher Resources at the end of this lesson

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Standard 12" ruler		1 per student	Already used 0n Day 2
Foam (polystyrene) gliders	The longer the wing span, the better.	1 per team	Already used on Day 3
Paper clips	These can be used as fasteners or weights if you should use smaller gliders.	1 box per class	Already used on Day 3
Duct tape		1 roll per class	Already used on Day 3
Hot glue gun		1 for every 2 teams	Already used on Days 4 and 5
Balsa wood		1 per team	Already used on Days 4 and 5
Foam board		1 per team	Already used on Days 4 and 5
Scrap cardboard		1 large box per team	Already used on Days 4 and 5
Very fine sanding blocks		1 per team	Already used on Days 4 and 5
Scissors		1 per team	Available in schools or office supply stores
Utility knives (optional)		1 per team	Available at hardware stores

Copy paper		1 ream	Available in schools or office supply stores
Poster Paper	For student presentations on Day 6	1 per team	Available in most schools

Day 6: Construction, Testing, and Optimization

Introduction (10 minutes)

As a class, review the criteria and constraints previously established for the design challenge. Then have students refer to 6.1: Build Day on page 19 in the Spy Gliders Student Handbook as they individually draw and label a detailed diagram of their final glider design. Be sure they include payload placement.

Design Work: Conceptual Model (15 minutes)

Instruct each student to share their design with other members of their team. Have them refer to 6.2: Conceptual Model on page 20 in the Spy Gliders Student Handbook as they work together to develop a detailed team model to present to the class.

Whole Group Discussion: Presentation and Class Discussion (20 minutes)

Have students refer to 6.2: Conceptual Model on page 20 in the Spy Gliders Student Handbook. Invite each team to present their idea, and elicit constructive feedback from the class. Have each team consider which suggestions and recommendations they want to incorporate into their final glider design.

Lesson Close (5 minutes)

Have students complete the 6.3: Build Day Debrief reflection activity on page 21 in the Spy Gliders Student Handbook. As time allows, discuss as a class.

Day 7: Construction, Testing, and Optimization

Design Work: Retool Team Glider Design (10 minutes)

Instruct teams to use the feedback received after their presentations on Day 6 to update their glider designs. Review and sign off on each team's updated design blueprint.

Design Work: Glider Construction (40 minutes)

Working in teams, have students use the provided supplies to construct their gliders and conduct preliminary, undocumented flight tests. During these initial tests, students should focus on air worthiness and throwing methods.

Day 8: Construction, Testing, and Optimization

Introduction (10 minutes)

Instruct students to turn to 8.1 Test Day on page 22 in the Spy Gliders Student Handbook. Have students respond to the writing prompt, which focuses on the design challenge's criteria and constraints, as well as the students' predictions. When finished, discuss as a class.

Design Work: Glider Testing and Data Collection (40 minutes)

Using the predetermined procedure, have student teams fly their gliders and gather data on 8.2: Test Day: Data Table on page 23 in the Spy Gliders Student Handbook.

Engage students in a discussion regarding the engineering design process. Choose from some of the prompts below, or create your own prompts.

- *Why is it important to engage in multiple tests?*
- *What is the purpose of redesign?*
- *Why gather input from other's on your design?*
- *What types of engineers might be involved in the development of a real airplane? Why?*
- *How did the criteria and constraints impact your design?*
- *How might a varying payload (weight, height, width) affect your design?*
- *Why might building a scale model be important before constructing the final product?*
- *How did the four forces of flights affect each glider's flight?*
- *When engineers design and build something, does it usually work as intended the first time? Why or why not?*
- *What can we learn from failure?*
- *How does each team member's role affect the glider testing?*

Day 9: Construction, Testing, and Optimization

Introduction (10 minutes)

Instruct students to turn to 9.1: Redesign and Retest on page 24 in the Spy Gliders Student Handbook. Have students respond to the prompt, which focuses on design strengths and failure points. Afterwards, discuss as a class.

Design Work: Optimize and Retest Gliders (20 minutes)

Allow the student teams to redesign and fly their optimized gliders. Have students gather data using the 9.2: Redesign and Retest: Data Table II on page 25 in the Spy Gliders Student Handbook. Afterwards, have students complete 9.3: Optimal Design on page 26 in the Spy Gliders Student Handbook.

Extension

Once the gliders prove to be air worthy, experiment with the placement of the added dummy weight. Once that design is optimized, the camera should be added to the body of one of the more successful gliders. At that point, the fully equipped glider can be flown from a high spot (upper story window, top of the bleachers, weather balloon, or other location) on school grounds to capture footage that can be shared with the entire class.

Design Work: Analyze and Make Inferences (20 minutes)

Direct students to analyze their testing results on 9.4 Analysis of Results on page 27 in the Spy Gliders Student Handbook. Instruct students to reflect on their previous drawings, and then identify and write at least three modifications to their glider design. They should also provide reasoning for the modifications based on testing evidence. Have students predict how each modification might impact test results.

Assessment

Several opportunities for formative assessment exist in this lesson:

- Spy Gliders Student Handbook entries can be used to monitor student progress during the module. For this lesson, focus on all Days 6 through 9 documents to monitor student progress.
- Consider using the Collaborative Work Skills Rubric (Appendix D) to assess student collaboration.

- Whole class share-outs and discussions allows for formative assessment of student ideas and building content knowledge.
- When students are meeting in their teams, spend time with each team, listening in on their process and providing support as needed.

Use the identified assessment opportunities to monitor student progress on disciplinary core ideas, science and engineering practices, and crosscutting concepts. Provide appropriate supports or extensions when necessary.

Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

Days 6 through 9 provide excellent opportunities for parents, community partners, and other adults to assist with student work. Additional adults can help monitor student activity during the design and testing stages.

Suggested Teacher Resources

Meeting the Needs of All Learners	Spy Gliders Teacher Handbook, Appendix B
Collaborative Work Skills Rubric	Spy Gliders Teacher Handbook, Appendix D

Spy Gliders
Day 10: Final Presentation

Grade Level	Middle School
Lesson Length	One 50-minute sessions

Lesson Overview

In this culminating lesson, student teams present a synopsis of the learning that has occurred throughout the module. Each presentation includes a description of the project in students' own words, an explanation of the science concepts applied, how each team improved on their design, and how the product they designed could be applied in real-life applications. The presentations should also include what students have learned about the field of engineering. The presentations involve both verbal and visual elements that are scored using a rubric.

Connecting to the Next Generation Science Standards

On Day 10, students demonstrate understanding of the performance expectations and three dimensions developed throughout the module. This lesson serves as a performance assessment in which all of the performance expectations and dimensions are addressed in the final presentation. Reference the performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts referenced in the front matter of this module.

Basic Teacher Preparation

During this culminating lesson, students present their findings and reflect on the Spy Gliders project. Review the Presentation Rubric in Appendix C.

Required Preparation	Links/Additional Information
❑ Download, print, and copy the Presentation Rubric	Refer to the Spy Gliders Teacher Handbook, Appendix C

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Presentation Rubric		1 per team	Spy Gliders Teacher Handbook, Appendix C

Day 10: Final Presentation

Introduction (5 minutes)

Tell students they present their work on Day 10. Encourage students to determine team work assignments to ensure that each presentation includes the following Presentation Guidelines.

Presentation Guidelines

- Description of the project in their own words
- Explanation of the science concepts applied (forces and motion)
- Description of how the team improved on their design and how the product they designed could be applied in real-life applications
- Summary of what students have learned about the field of engineering
- Final model of their design with descriptions of forces and motion

Review the Presentation Rubric (Appendix C) with students before they begin their work.

Design Work: Presentation Planning (20 minutes)

Allow student teams to prepare their presentations. Depending on time constraints, students can either give their presentations to other engineering teams or to the whole class. Score presentations using the provided Presentation Rubric (Appendix C).

Helpful Tip

If needed, consider adding an additional day for students to prepare and give their presentations.

Whole Group Discussion: Final Presentations (20 minutes)

Have student teams present their findings.

Helpful Tip

Consider creating a simplified Presentation Rubric for student teams to score other teams as they present.

Lesson Close (5 minutes)

Have students record their thoughts on the following prompts in an exit ticket or class science journal:

- *Did you enjoy this module? Why or why not?*
- *What did you learn from it?*
- *What surprised you about the engineering design process?*
- *After this, what would you like to learn/study next?*

Assessment

The final presentation can be used as a summative assessment for the module. Consider using the Presentation Rubric in Appendix C to assess the final presentations.

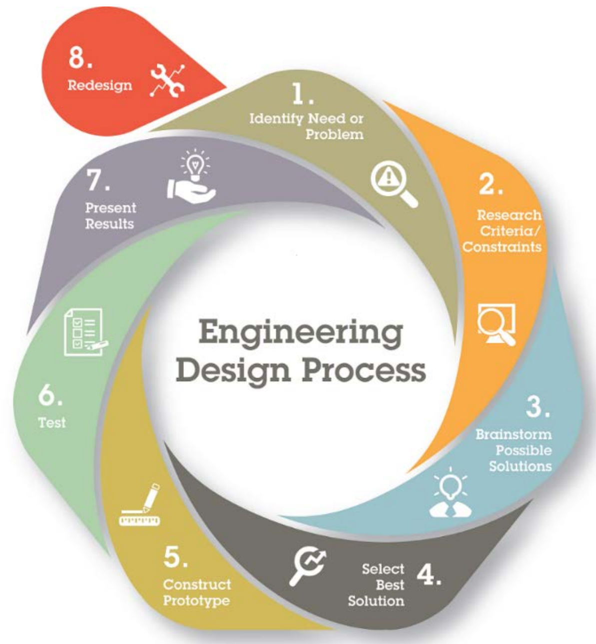
Community Connections

Consider having students present and defend their designs as part of a “high stakes” showcase engineering design presentation to invited engineers, designers, and entrepreneurs.

Suggested Teacher Resources

Presentation Rubric	Spy Gliders Teacher Handbook, Appendix C

Appendix A
Engineering Design Process



Step 1 Identify the Need or Problem

Describe the engineering design challenge to be solved. Include the limits and constraints, customer description, and an explanation of why solving this challenge is important.

Step 2 Research Criteria and Constraints

Research how others have solved this or similar problems, and discover what materials have been used. Be sure to thoroughly research the limitations and design requirements for success.

Step 3 Brainstorm Possible Solutions

Use your knowledge and creativity to generate as many solutions as possible. During this brainstorming stage, do not reject any ideas.

Step 4 Select the Best Solution

Each team member presents their solution ideas to the team. Team members annotate how each solution does or does not meet each design requirement. The team then agrees on a solution, or combination of solutions, that best meets the design requirements.

Step 5 Construct a Prototype

Develop an operating version of the solution.

Step 6 Test

Test your solution. Annotate the results from each test to share with your team.

Step 7 Present Results

Present the results from each test to the team.

Step 8 Redesign

Determine a redesign to address failure points and/or design improvements. The design process involves multiple iterations and redesigns. Redesign is based on the data from your tests, your team discussions as to the next steps to improve the design, and the engineering design process Steps 1 through 7.

Once your team is confident of a prototype solution, you present the results to the client. The client may:

- Accept your solution as is, or
- Ask for additional constraints and criteria to be included in the solution. At this point, you and your team revisit the engineering design process and resume the iterative redesign cycle.

Appendix B
Meeting the Needs of All Learners

Every learner is unique. To meet the needs of all learners in your class, consider the following strategies:

- Provide students with sentence stems for models, arguments, and explanations (see below).
- Use a graphic organizer to help students organize their thinking prior to creating their final presentation (see below).
- Prior to each group discussion, engage students in individual or small group discussions to help them prepare to share their ideas in a larger group.
- Provide students with a vocabulary list using the Glossary.
- Offer additional extension problems or challenges in math or science.
- Provide students with additional time to formulate their ideas prior to sharing with the class.
- Offer opportunities for students to engage in additional investigations to extend learning. This may include additional readings, science investigations, or research.

Design Problem:
Science Ideas related to the Design Problem:
First Draft Design Solution: *Reflection/Modifications Needed:*
Second Draft Design Solution: *Reflection/Modifications Needed:*
Final Design Solution and Justification:

Sentence Stems

Contributed by Karl Muench, Collins Middle School, Salem, MA

Claim

You frame the question and answer it. This may take a sentence or a paragraph. Examples of claim sentences include the following.

- Analysis (breaking down the elements)
  - Our analysis looked at the parts and their function in …
  - We know from our data that … is comprised (made of) …, … and …
- Comparison (similarities and differences)
  - … (A) and … (B) are alike in that both …
  - However, while … (A) does this …, the other, … (B), does this …
- Evaluation (testing against a set of rules)
  - The … (subject of study) best matched the rule that …
  - In the situations involving …, the … (subject of study) showed …
- Problem/solution
  - … is a problem, and the best solution is …
  - Very often, … will have a problem with … The way to fix it is …
- Cause/Effect
  - … causes … to happen.
  - … is created when …
  - … if … then …

Give a preview of how you will prove your claim. Follow the above statements with the word ***because***.

Evidence

Include research and results of demonstrations or your own experimentation that support your claim. In science, you need to cite ALL available evidence, even some that may work against your claim. (You can deal with that issue by using reasoning.)

- Analysis
  - We conducted this experiment … The results are shown in the following table.
  - We graphed … over … and saw this pattern …
  - In most cases, we saw … Sometimes, however, … would happen.
  - We found the following analysis of this in our research … (direct quotes with sources)
- Comparison
  - We compiled the following T-chart showing where these things are alike and unalike.
  - In this Venn diagram, we can see where these things are similar and different.
  - In both cases, … is true. But only for ... is … true.
  - We have both things on this graph. You can see here … where they meet.
- Evaluation
  - We were looking for the following criteria … The following met those criteria … The following did not meet those criteria …
  - The rule … applies to the following … and does not work for …

  - Scientists say … (quotation with source). We found this applied to ...
- Problem/Solution
  - These sources … point to this issue …
  - We tested our prototypes by … These were the results …
  - Experts such as … (sources) say … is a common problem.
  - … (source) emphasizes that … is a problem, with this possible solution ...
- Cause/Effect
  - Every time … happened, … would happen.
  - Scientists believe that … is caused by … (quote with source)
  - The following graph shows how … influences …
  - This chart shows when … happens (or is present) and what happens next.
  - Statistics indicate that ...

Reasoning

You need to explain in your own words how your evidence supports your claim. In the case of evidence that contradicts your claim, you must explain why other evidence has more merit or reliability.

- Analysis
  - The evidence supports our claim because …
  - The graph shows that as … rises, … rises/falls at a (steady or increasing) rate. This allows us to predict …
  - Taking the evidence as a whole shows …
- Comparison
  - These things behave similarly when … but differently when …
  - Considering these similarities and differences indicates …
  - Looking at the chart of evidence, we see how … is similar to …, but different in ...
- Evaluation
  - If … is true, we should see … This is exactly what we see in the case(s) of …
  - Every time (or almost every time) we tried this …, this happened …
  - ... did not meet our criteria as well as …, eliminating it as an option.
- Problem/Solution
  - As you can see, our test (or research) indicates this solution will solve the problem because …
  - Our research and testing found … can best solve this problem by …
  - We were looking for this … and found it in ...
- Cause/Effect
  - The evidence shows that … causes … because …
  - Looking at the data, we see that … followed … every time.
  - Our research shows that scientists support that … causes … because ...
- Dealing with contrary evidence
  - By looking at all of this, we can see that these data … are outliers.
  - While some scientists say …, most scientists agree that …
  - Some of our results are less reliable because ...

Appendix C
Presentation Rubric

The Presentation Rubric is intended to be used as a guide for the development of the assessment for the final presentations. Teachers should tailor the rubric to fit the module's specific needs and design problem.

Science and Innovation
A Boeing and Teaching Channel Partnership
PRESENTATION RUBRIC

	No Evidence	Beginning	Developing	Advanced
Quality of Design Product NOTE: This section should be tailored to assess specific module and performance expectations.	Design product fails to address most aspects of the performance task. Design product shows no evidence of thoughtful problem solving. Design product shows evidence of low-quality craftsmanship.	Design product addresses some aspects of the performance task. Design product shows little evidence of thoughtful problem solving. Design product shows evidence of mediocre-quality craftsmanship.	Design product addresses most aspects of the performance task. Design product shows some evidence of thoughtful problem solving. Design product shows evidence of mostly high-quality craftsmanship.	Design product addresses all aspects of the performance task. Design product shows clear evidence of thoughtful problem solving, deliberation, and decision making. Design product shows clear evidence of high-quality craftsmanship.
Explanation of Science Ideas Science ideas include science and engineering practices, disciplinary core ideas, and crosscutting concepts. NOTE: This section should be tailored to assess specific module and performance expectations.	Relevant science ideas are not addressed. Evidence is not cited.	Most relevant science ideas are stated and partially described in relation to the design problem. Some evidence is cited. Evidence was gathered through science investigations or critical analysis of existing sources.	All relevant science ideas are stated and described in relation to the design problem. Several lines of evidence are cited. Evidence was gathered through science investigations or critical analysis of existing sources.	All relevant science ideas are clearly stated and described in detail in relation to the design problem. Multiple lines of evidence are cited. Evidence was gathered through science investigations or critical analysis of existing sources.
Organization	The presentation does not include all of the required components. The presentation does not have a main idea or presents ideas in an order that does not make sense.	The presentation includes most of the required components. The presentation moves from one idea to the next, but the main idea may not be clear or some ideas	The presentation includes all of the required components. The main idea is clearly stated. The presentation moves from one idea to the next in a logical order, emphasizing main	The presentation includes all of the required components and either provides additional information for each component or adds additional components relevant to the presentation.

		may be in the wrong order.	points in a focused, coherent manner.	The main idea is clearly stated. The presentation moves from one idea to the next in a logical order, emphasizing the main points in a focused, coherent manner. (CC 6-8. SL.4)
Presenting Skills	The presenter does not look at the audience and reads notes or slides. The presenter wears clothing inappropriate for the occasion. The presenter mumbles or speaks too quickly or slowly. The presenter speaks too softly to be understood.	The presenter makes infrequent eye contact and reads notes or slides most of the time. The presenter dresses professionally. The presenter speaks clearly most of the time, although sometimes too quickly or slowly. The presenter speaks loudly enough for most of the audience to hear, but may speak in a monotone.	The presenter keeps eye contact with audience most of the time and only glances at notes or slides. The presenter dresses professionally. The presenter speaks clearly and not too quickly or slowly. (CC 6-8.SL.4) The presenter speaks loudly enough for everyone to hear and changes tone to maintain interest. (CC 6-8.SL.4)	The presenter engages the audience by drawing their sustained attention. The presenter maintains eye contact with the audience most of the time and only glances at notes or slides. (CC 6-8.SL.4) The presenter dresses professionally. The presenter speaks clearly and not too quickly or slowly. (CC 6-8.SL.4) The presenter speaks loudly enough for everyone to hear and changes tone to maintain interest. (CC 6-8.SL.4)

Appendix D
Collaboration Rubric

Check Appropriate Box: ☐ Teacher Evaluated ☐ Self-Evaluated ☐ Peer Evaluated ☐Group Evaluated

Teacher Name: ___________ Student Name: ______________________________________ Period: ________

Date: ___________ Group Members: ____

Project / Activity: ____Due Date: ____________

	4	3	2	1	0
Collaboration	Routinely provides useful ideas when participating in group activities and discussions. A definite leader who contributes a lot of effort.	Usually provides useful ideas when participating in group activities and discussions. A strong group member who tries hard.	Sometimes provides useful ideas when participating in group activities and discussions. A group member who mostly does what is required.	Rarely provides useful ideas when participating in group activities and discussions. Minimal participation and frequent distractions limit group success.	Little or no effort shown.
Time Management	Routinely uses time well throughout the project to ensure tasks get done on time. Group does not have to adjust deadlines or work responsibilities because of this person's procrastination.	Usually uses time well throughout the project, but may have procrastinated on one task. Group does not have to adjust deadlines or work responsibilities because of this person's procrastination.	Tends to procrastinate, but always gets tasks done by the deadlines. Group does not have to adjust deadlines or work responsibilities because of this person's procrastination.	Rarely gets tasks done by the deadlines, AND group has to adjust deadlines or work responsibilities because of this person's inadequate time management.	Little or no effort shown.
Problem-Solving	Actively looks for and suggests solutions to problems.	Refines solutions suggested by others.	Does not suggest or refine solutions, but is willing to try solutions suggested by others.	Does not try to solve problems or help others solve problems. Lets others do the work.	Little or no effort shown.
Preparedness	Brings needed materials to class and is always ready to work.	Almost always brings needed materials to class and is ready to work.	Almost always brings needed materials but sometimes needs to be redirected get to work.	Often forgets needed materials or is rarely ready to get to work.	Little or no effort shown.

Attitude	Never is publicly critical of the project or the work of others. Always has a positive attitude about the task(s).	Rarely is publicly critical of the project or the work of others. Often has a positive attitude about the task(s).	Occasionally is publicly critical of the project or the work of other members of the group. Usually has a positive attitude about the task(s).	Often is publicly critical of the project or the work of other members of the group. Often has a negative attitude about the task(s).	Little or no effort shown.
Focus on the Task	Consistently stays focused on the task and what needs to be done. Very self-directed.	Focuses on the task and what needs to be done most of the time. Other group members can count on this person.	Focuses on the task and what needs to be done some of the time. Sometimes difficult to keep this person on-task.	Rarely focuses on the task and what needs to be done. Lets others do the work.	Little or no effort shown.
Score:					
Total:					

Glossary

The key terms below are frequently used in the module. Students should develop a strong conceptual understanding of each term throughout the module. Definitions are from oxforddictionaries.com.

center of gravity	The center of gravity is a geometric property that serves as the average location of the weight of an object.*
center of mass	The center of mass is the point where all of the mass of the object is concentrated. When an object is supported at its center of mass, no net torque acting on the body and it will remain in static equilibrium.**
Constraints	Limitations or restrictions.
criteria	A standard of judgment or criticism; a rule or principle for evaluating or testing something.
drag	The force that acts opposite to the direction of motion. It tends to slow an object. Drag is caused by friction and differences in air pressure. An example is putting your hand out of a moving car window and feeling it pull back.*
equilibrium	A state of rest or balance due to the equal act of opposing forces.
lift	The force that holds an airplane in the air. The wings create most of the lift used by airplanes.*
material	The substance or substances of which a thing is made or composed.
newton	The standard unit of force in the International System of Units (SI), equal to the force that produces an acceleration of one meter per second per second on a mass of one kilogram.
optimize	To make as effective, perfect, or useful as possible.
thrust	A force that moves an aircraft in the direction of the motion. It is created with a propeller, jet engine, or rocket. Air is pulled in and then pushed out in an opposite direction. One example is a household fan.*
weight	The force that gravitation exerts on a body, equal to the mass of the body times the local acceleration of gravity; commonly taken, in a region of constant gravitational acceleration, as a measure of mass.

** Definition developed by NASA (www.nasa.gov)*

*** Definition developed by Physics Lab (www.physicslab.org)*