Engineering Practices in Action

Session Time: Three, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

Develop interest in one or more aviation/aerospace career pathways and learn what is required to pursue future employment in the industry. (EU3)

Aspire to the highest level of technical proficiency as it relates to flight operations and engineering practices. (EU5)

ESSENTIAL QUESTIONS

- How do engineers develop viable solutions for complex problems?
- How did the crew of Apollo 13 solve their life-threatening challenges under extreme conditions?

LEARNING GOALS

Students Will Know

- The eight practices engineers use to solve challenges.
- The problems and constraints the crew of Apollo 13 faced and their attempts to solve them.
- How to use engineering practices to solve unique problems.

Students Will Be Able To

- *Apply* engineering practices in order to investigate, evaluate, and develop solutions for a problem. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Students will consider how they solve problems and identify the strategies they use.

Formative Assessment
Students will analyze how engineering practices were used to solve a crisis during the Apollo 13 mission.

Summative Assessment
Students will reflect on the process they used in the design challenge and report on the practices used and challenges they had to overcome.

LESSON PREPARATION

MATERIALS/RESOURCES

- Engineering Practices in Action Presentation
- Engineering Practices in Action Student Activity 1
- Engineering Practices in Action Student Activity 2
- Engineering Practices in Action Teacher Notes 1
- Engineering Practices in Action Teacher Notes 2

Heavy Lift Rocket Activity (per group)

- Large binder clip
- Fishing line/smooth string
- 4 long balloons - 5” 24” or 3” 60”
- Bathroom size (3 o.z.) paper cup
- 2 straight drinking straws
- 50 small paper clips
- Sandwich-size plastic bag
- Masking tape
- Wooden spring-type clothespins (optional)
- Scissors

SAFETY

Actively supervise students during the lab or activity. Be ready to offer guidance in situations where safety could be compromised.

LESSON SUMMARY

Lesson 1: Introduction to Aerospace Studies
Lesson 2: Engineering Practices in Action
Lesson 3: Aviation Careers Are For You!

In the first session, students will start with a warm-up by considering how they solve problems and identify the strategies they use. A class discussion will introduce students to engineering practices. Specifically, students will learn about the crisis that occurred during the Apollo 13 mission. They learn about the engineering practices within this context and discuss why each one was relevant and important.

Students will take the discussion of Apollo 13's crisis further by learning how the ground team and astronauts worked together to solve critical problems. They will then complete an activity analyzing the ways in which the astronauts and the ground team used engineering practices.

Finally, in the second and third sessions, students will work in teams to design the next generation of “heavy lift rockets” to carry a payload to the ceiling by applying the engineering practices.

Students will design balloon-powered rockets to launch the greatest payload possible to the classroom ceiling. Student teams will receive identical materials with which to construct their rockets. The team that launches the heaviest payload (number of paper clips) to space (the ceiling) wins!

BACKGROUND

This lesson will introduce students to engineering practices, which will be embedded throughout the curriculum. These practices have been identified to develop students' "scientific habits of mind" and to grow their skills as problem solvers and critical thinkers. As students learn how to apply engineering practices, their questions should become more relevant and focused. Facilitating such evolution requires a classroom culture that values good questions and offers students opportunities to refine their questions and strategies. As a result, students will become increasingly proficient at posing questions that seek relevant evidence, work to refine an engineering problem, or challenge the feasibility of a design. More information about these practices are found in "A Framework for K-12 Science Education", which is available online at no charge.

This lesson includes an engaging engineering design activity called "Heavy Rocket Launch Activity". Launching supplies and equipment into space is very expensive and is often the limiting factor in the ability to expand exploration farther into space, or, launching more frequently. The development of more efficient heavy lift rocket systems would help lower the cost (per pound) of space operations and enable missions like a permanent base on the moon or even a human mission to Mars. This lesson draws upon this reality to challenge students' creativity in helping develop ideas for improved heavy lift rocket systems.

MISCONCEPTIONS

Many students have the mistaken impression that there is one distinctive approach common to all science—a single "scientific method". In reality, practicing scientists and engineers employ a broad spectrum of methods, and not necessarily in a particular order.

DIFFERENTIATION

To promote reflective thinking and guided inquiry for struggling readers, circulate around the classroom and assist students who might have trouble coming up with ideas during the activity in the third session. Ask questions that provoke their own ideas for possible answers.

To support verbal reasoning in the class discussion, organize the class into groups for Think-Pair-Share instead of a whole group discussion. This allows learners to think about the question, and discuss their thoughts with a partner before sharing with the larger group. Sharing encourages all students to participate and practice skills, including metacognition.

LEARNING PLAN

ENGAGE

Teacher Material: Engineering Practices in Action Presentation

Slides 1-3: Introduce topic and the learning objectives for this lesson. Explain that the class will look at a case study of engineering practices "in action."

Slide 4: Conduct the **Warm-up.**

Warm-Up

Ask students to recall a problem that they recently had to solve and then write down three strategies that they used to solve this problem.

After students write down their three strategies, ask them to share them with the class and record them on the board. Ask students to group together strategies that are common (for use later as a lead-in to engineering practices).

[DOK-L1; recall, list]

EXPLORE

Teacher Material: Engineering Practices in Action Presentation

Slide 5: Play students a video which shows the attempt to return the crew of the Apollo 13 mission safely to earth following an explosion on board the service module. Ask students to make a list of ways they observe the NASA employees solving problems as they watch the video.

- "Houston, We've Got a Problem" (Length 28:20, play the first 7 minutes, 32 seconds) http://video.link/w/abLd

Slide 6: Ask students to discuss these two questions with a partner.

Questions

1. What was the problem the astronauts faced?
The astronauts heard an explosion or "bang" in their aircraft, noticed that they had a problem with the "Main Bus B Undervolt" (power supply malfunction), had an instrumentation problem, and their spacecraft was venting something unknown into space.

2. What specific things did the NASA team do to try to solve the problem?
Students' answers will vary:

- *Identify what happened*
- *Make observations*
- *Share details of observations with others*
- *Share prior history of observations given the same circumstances*
- *Team work*
- *Ask questions*
- *Review and analyze data*
- *Try to narrow down possibilities of what occurred*
- *Make more observations*
- *Ask different team members for their perspective and suggestions*
- *Get more help from others*
- *Keep cool*
- *Determine what is essential to complete the mission*

Slide 7: After watching the video, have students share the strategies they wrote down for how NASA employees solved problems. Write this list on the board for later use. Then, ask students what happened aboard Apollo 13.

Apollo 13 was the third mission sent to land on the moon's surface, but unforeseen events kept that from happening. In the spring of 1970, during their second day in space, the Apollo 13 crew had just finished making a television broadcast showing people on Earth how cool it was to live and work in weightlessness. Nine minutes after completing the transmission, the crew heard a loud bang accompanied by warning lights indicating an electrical problem. Command

Module pilot Jack Swigert uttered the phrase that would become famously associated with this mission, "Houston, we' ve had a problem…"

The noise they heard was an explosion that destroyed one of the spacecraft's main oxygen tanks and damaged the other. Within hours the Command Module (CM) was running low on power because there wasn't enough oxygen to run the power cells that generated electricity for the spacecraft. Without electricity, there was no heat—and space is really cold!

Slide 8: The three astronauts squeezed into the undamaged Lunar Module (LM). The challenge was that the LM was designed for two people. They were running low on water, electricity, and fresh air. Spacecraft have an air scrubbing device that can remove carbon dioxide (CO2) from the air to keep it fresh enough for humans to breathe, but having three people in a craft designed for two meant the scrubber couldn't keep up. The astronauts needed a fix if they were going to make it back to Earth.

Explain that the only way the astronauts could make it back alive was for the command center and the astronauts to quickly employ engineering practices in order to solve the problem.

EXPLAIN

Teacher Materials: Engineering Practices in Action Presentation. Engineering Practices in Action Teacher Notes 1
Student Material: Engineering Practices in Action Student Activity 1

Slide 9: A class discussion will introduce students to engineering practices, which will be embedded throughout all the curriculum. Explain to students that engineering practices are ways of thinking used to solve an engineering problem. These practices will be embedded in all design activities throughout the courses. The main idea is that the practices are not used in a certain order, a certain amount of times, or always used. They can be drawn from as many times as needed and are often used repetitively in an iterative fashion.

Slide 10: Engineering practices fit within "three spheres of activity" - investigating, evaluating, and developing explanations and solutions. Engineers draw from the strategies in these spheres to best meet the situation at hand.

Investigate - Students will practice asking questions to better understand the problem. They will determine what tools and materials they have access to and what they are trying to solve. They will determine how to best develop a solution through designing a test, conducting experiments, measuring and collecting data, and refining their model.

Evaluate - Students will learn how to reason by using data and observations as evidence ("argue"). They also will provide feedback and suggestions to others' arguments. This feedback should be constructive and helpful. This part of the engineering practices is often under-emphasized and is important for building new understanding.

Develop explanations and solutions - Students should develop a hypothesis and predict what is likely to occur. They will use reasoning and models to develop solutions.

Slide 11: The diagram displays the three spheres of activity for scientists and engineers: Investigating, evaluating and developing solutions. Of utmost importance is sharing with students that they will move back and forth within these three spheres. Their process may be iterative where they are constantly refining their explanations or design.

In one sphere, the dominant activity is investigation and empirical inquiry.

In the second, the essence of work is the construction of explanations or designs using reasoning, creative thinking, and models.

And in the third sphere, the ideas, such as the fit of models and explanations to evidence or the appropriateness of product designs, are analyzed, debated, and evaluated.

In all three spheres of activity, engineers try to use the best available tools to support the task at hand.

Engineering practices support these activities by continuing to apply questioning, reasoning and analysis, iteratively and fluidly across all three.

Slide 12: Share the engineering practices with your students. Inform students that they will consider these eight essential practices of engineering in more depth in the second session of this lesson.

Compare this list to the "groups" students developed during the warm-up.

- Define problems
- Develop and use models
- Plan and carry out investigations
- Analyze and interpret data
- Use mathematics and computational thinking
- Constructing Explanations and Designing Solutions
- Engage in argument from evidence
- Develop and use new models
- Carry out investigation
- Obtain, evaluate, and communicate information

Slides 13-17: Provide more detail on each of the engineering practices.

Questions will assist students in understanding the problem and define what it is they are trying to solve.

Models can mean three-dimensional models, drawings, sketches, computer simulation, etc.

Students need to consider how they will maintain consistency in testing, how precise their measurements will be and how they will collect and record data. Data is not always quantifiable, it can also mean collecting observations. Students need to know that engineers use a model in testing in an effort to assess how a full size component would respond. Reasons for using models vs "the real thing" varies—cost savings, safety, and efficiency are a few.

Students will determine how to organize data to analyze it. Students should look for patterns and relationships between variables.

Mathematical models may mean using equations to represent the data or test relationships between variables. In the case shared today, it might mean mathematical concepts.

Explanations should be constructed based on evidence provided by data and observations.

Scientific arguments should be presented and receive productive and respectful criticism. Additional questions can be asked in order to fine tune the solution.

How do engineers communicate their solutions? They share observations including data and provide evidence from testing. They sometimes list steps, create diagrams, use tables, present explanations to share their conclusions.

Remind students not every engineering problem may require that every specific engineering practice be used. In some cases, they will be used multiple time or maybe not at all.

Slide 18: Conduct the **Formative Assessment.**

Formative Assessment

Distribute **Engineering Practices in Action Student Activity 1**. This may be provided as homework. Use **Engineering Practices in Action Teacher Notes 1** to assist you in evaluating the student activity.

Collect the activity sheets from each student. Score up to 10 points based on completion and evidence of participation.

[DOK-L4; *analyze*, DOK-L3; *investigate*]

Slides 19-20: Review the answers to the first activity as a group and share images of the Apollo 13 ordeal.

Remind students that engineering practices can be completed in any order and may be repeated many times within a process. Practices fall into one of three categories:

- Investigating: The dominant activity is the investigation.
- Developing Solutions: The essence of work is the construction of designs using reasoning, creative thinking, and models.
- Evaluating: The ideas, such as the fit of models and explanations to evidence or the appropriateness of product designs, are analyzed, debated, and evaluated.

If time allows, show students more footage from the documentary about Apollo 13 and use it as the basis for further discussion of engineering practices.

- "Houston, We've Got a Problem" (Length 28:20, play the remainder of the video) http://video.link/w/abLd

EXTEND

Teacher Materials: Engineering Practices in Action Presentation, Engineering Practices in Action Teacher Notes 2
Student Material: Engineering Practices in Action Student Activity 2

Slide 21: In the second and third sessions, students will take the engineering practices they have studied and apply them to a new project. For inspiration and ideas for the activity, show a SpaceX video of a heavy lift rocket.

- "See SpaceX's Falcon Heavy rocket land all 3 boosters for the first time" (Length 3:02) https://video.link/w/wxIyd

Slide 22: Place students in groups of three to four and provide copies of **Engineering Practices in Action Student Activity 2**. Outline the parameters of the project.

Students will work in teams to design, build, and test the next generation of "heavy lift rocket." During this activity, they will construct balloon-powered rockets to launch the heaviest payload possible to the classroom ceiling. Their challenge is to develop new ideas for launching heavy payloads into orbit.

Note that in real life, payloads could consist of parts, supplies, or the equipment needed to launch a mission to space. Having access to all the same materials, your students will build a heavy lift rocket system to carry the largest payload of paper clips into space (the ceiling). The team that carries the largest payload wins the contract!

Allow students the rest of the session to conduct their experiments.

Slide 23: Provide each team an identical set of materials and let them know they can use any or all of the materials provided.

Suspend fishing line or smooth string from your ceiling above each launch station. If you have a drop ceiling, use a clip to attach the string or line to the ceiling so it hangs straight down to the floor with enough space around it for students to work.

Help students understand the launch method. They will thread the line through their straw(s) so that it can smoothly guide their rocket to the ceiling. They will need to hold the string to the floor during launch to prevent any slack line from interfering with their rocket's trajectory.

Avoid giving too many hints. Let them use their ingenuity to develop solutions to the mission problem. Just show them how the launch system works, which materials they can use, and that they are limited to the supplies given at their station.

Have the students walk through the engineering practices and record their results on the activity sheet. Create a chart to keep track of results to determine the "contract winner."

Share the following tips with students after they have attempted a launch or two on their own.

- If the balloons have long nozzles, they will likely need to be modified. An effective way to do this is to cut the nozzle shorter. Students can experiment with what length is most effective.
- Have students observe the balloons carefully as they launch – even to the point of using the slow-motion video feature on their smartphones.
- Minimizing weight is critical to carrying higher payloads. Suggest ideas like cutting the guide straws shorter and using the minimum amount of tape.
- Balance also plays an important role in a successful launch. Suggest placing the guide straws about halfway up the balloon. Have the students experiment and observe. The main issue is stabilizing the rocket throughout its flight. They must devise a way to ensure the escaping air is always directed toward the ground to achieve maximum thrust.

Teaching Tips

Avoiding frustration is good, but letting them work through some failures is a valuable experience in developing problem-solving skills and helps to develop intellectual independence.

EVALUATE

Teacher Materials: Engineering Practices in Action Presentation, Engineering Practices in Action Teacher Notes 2
Student Material: Engineering Practices in Action Student Activity 2

Slide 24: Have each group provide a 1- to 2-minute explanation of how their design functions, what they learned through their testing, what modifications they made as a result, and how their rocket performed with particular reference to the engineering practices they used.

The teams should be prepared to defend the design choices they made, and also be ready to describe what limitations, errors, and ideas they have for moving forward with the design, as well as what they learned.

Conduct an end of lesson analysis and discussion. Assign the Summative Assessment for homework if short on time.

Teaching Tips

Be sure to debrief the activity with students. Ask them which engineering practices they used and how. Ask them if there is anything else they wish they had tried in their modifications. Ask if there are any questions related to the activity that are still lingering.

Slide 25: Conduct the **Summative Assessment**.

Summative Assessment

Respond to each question by writing three to four sentences.

1. What aspects of this activity proved to be the most challenging for your team?
2. In what ways did your team successfully employ engineering practices to address these challenges? Use specific examples and be sure to identify which engineering practice(s) you used.

Collect student work at the end of class and use the Scoring Rubric for grading.

[DOK-L3; *explain, critique*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Answers to questions shows evidence of one or more of the following
  - Knowledge of engineering practices.
  - Ability to employ engineering practices.
  - Ability to identify challenges when employing certain practices
- Shows understanding of concepts covered in the lesson.

Points	Performance Levels
9-10	Consistently demonstrates criteria
7-8	Usually demonstrates criteria
5-6	Sometimes demonstrates criteria
0-4	Rarely to never demonstrates criteria

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

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

    - Asking Questions and Defining Problems
    - Constructing Explanations and Designing Solutions
  - Disciplinary Core Ideas
    - ETS1.A: Defining and Delimiting Engineering Problems
  - Crosscutting Concepts
    - Systems and System Models
    - Influence of Science, Engineering, and Technology on Society and the Natural World
- **HS-ETS1-2** - Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
  - Science and Engineering Practices
    - Constructing Explanations and Designing Solutions
  - Disciplinary Core Ideas
    - ETS1.C: Optimizing the Design Solution
  - Crosscutting Concepts
    - none
- **HS-ETS1-3** - Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
  - Science and Engineering Practices
    - Constructing Explanations and Designing Solutions
  - Disciplinary Core Ideas
    - ETS1.B: Developing Possible Solutions
  - Crosscutting Concepts
    - Influence of Science, Engineering, and Technology on Society and the Natural World

COMMON CORE STATE STANDARDS

- **RST.9-10.1** - Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
- **RST.9-10.2** - Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- **RST.9-10.4** - Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.
- **RST.9-10.7** - Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.
- **WHST.9-10.2** - Write informative/explanatory texts, including the narration of historical events, scientific procedures /experiments, or technical processes.

- **WHST.9-10.4** - Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

- **WHST.9-10.6** - Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.
- **WHST.9-10.7** - Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- **WHST.9-10.8** - Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- **WHST.9-10.9** - Draw evidence from informational texts to support analysis, reflection, and research.

REFERENCES

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