National Aeronautics and Space Administration

STEM LEARNING:

X-57 Maxwell Electric Plane Educator Guide

www.nasa.gov

STEM LEARNING EDUCATOR GUIDE: X-57 MAXWELL ELECTRIC AIRPLANE

This STEM Learning Guide uses NASA's X-57 Maxwell electric airplane project as a phenomenon for learning about alternative energy, physics, engineering and teamwork. In this module, students will learn about NASA's latest X-plane, by watching NASA animations, completing hands-on activities, and completing digital challenges. The X-57 uses alternative energy and innovative design to fly without aviation fuel with wings that provide five time as much lift as expected.

Big Science and Engineering Challenges

1. Alternative Energy Challenge: Can you build a working battery? How can you prevent battery fires and explosions? *(Lesson 1 and 2)*

2. Engineering Challenge: Can you design and build a wing for an airplane? Can you test your wing in a wind tunnel? *(Lesson 3)*

3. Teamwork Challenge: Can you use work together as a team—a skill all NASA missions require—during the engineering design process? *(Lesson 4)*

Learning Activities

These three learning activities will help students understand the engineering design of the X-57 all-electric airplane, and teamwork skills necessary to get the project "off the ground."

1. How batteries can safely replace aviation fuel and power an airplane: Students safely build and test batteries to understand how batteries store and release energy. Students complete the UL Xplorlabs Portable Electric Power module about destructive battery testing and thermal runaway.

2. How changing an airplane's wing design and adding small motors can increase lift and reduce drag. Students investigate the four forces of flight on a wing. Students use a wind tunnel or simulator to test a traditional wing design compared to the high-lift wing used on the X-57, using a wind tunnel or simulator.

3. Teamwork for engineering design: What's the story? What skills are needed? Students use NASA's Expeditionary Skills resources to learn how teamwork is a critical part of any NASA mission or school project.

STEM Background

The two main STEM concepts are energy transfer, and the physical science of pressure and aerodynamics. The X-57 case study represents a discrepant event—an airplane that flies more efficiently on a lower energy power source-aviation fuel versus electrical energy stored in lithium ion batteries, and a smaller wing that has five times the lift of a larger wing.

The other important story is how, through teamwork and engineering design, innovative solutions can address the scientific discrepancies. You may wish to begin with the teamwork modules, or work through them while you're completing the other activities.

Recommended Sequence

1. Students navigate through the X-57 website, then complete the 10-question review. *(See next page)*

2. In groups, complete a K-W-L about the X-57 design process, recording what the students already Know, and what they Want to know. Compile all of the unanswered questions, and record on poster hung in the classroom.

3. Instructor will then select the activities they want to use. Each activity can be completed in one class period or can be extended as described.

4. At the conclusion of the learning activities, return to the unanswered questions poster and discuss what is now known and still unknown. Record what students Learned on the K-W-L poster.

STEM LEARNING: X-57 MAXWELL ELECTRIC AIRPLANE

What is NASA's new X-57 Maxwell plane?

Navigate the X-57 presentation. https://www.nasa.gov/specials/X57/index.html

Read carefully and take notes. Then answer these X-57 questions.

(An answer key is on last page)

1. Why is NASA developing this technology?
2. What is unique about this aircraft?
3. Why is it called the Maxwell?
4. What are the two kinds of motors, and when are they used?
5. What kind of batteries will be used, and how are they tested?
6. How is the wing "tricked" into behaving as if it had a larger area?
7. What was the first real-world test of this technology?
8. What are the environmental benefits of this technology?
9. What is "thermal runaway?"
10. To increase the X-57's energy efficiency, the force we need to increase is _________, and the force we need to decrease is ___________.

EDUCATIONAL ACTIVITIES

NASA NOTES
The X-57 gets all the energy needed to power the airplane from batteries. NASA scientists researched many different kinds of batteries and many different arrangements of batteries to find a combination with enough long-lasting power. Now it's your turn!

Students will watch this animation about batteries.

https://www.youtube.com/watch?v=jgfceqwqUec&list=PLiuUQ9asub3TogGec4FJsGaXWjeGK5Ff8&index=2

Students have researched X-57, and battery power. They can now begin:

Lesson 1: Construct a battery
Lesson 2: Digitally test portable electric device
Lesson 3: Physics of flight
Lesson 4: Teamwork and project skills

LESSON 1: HOW DO BATTERIES STORE AND TRANSER ENERGY?

TASK

Build a basic battery from pennies and a salt/vinegar solution, and test battery voltage using LED lights and a voltmeter.

Coin Battery Lab Instructions

Students will watch this video demonstrating the coin battery lab instructions.

https://www.youtube.com/watch?v=7UrsO9QBFXA&index=3&list=PLiuUQ9asub3TogGec4FJsGaXWjeGK5Ff8

Each group needs:

- 5-10 pennies made after 1982
- 100-grit sandpaper
- Mat board or cardboard
- Vinegar
- Salt
- High intensity red and blue LED lights
- Voltmeter
- Electrical Tape
- Scissors
- Paper Towel
- Mixing cup
- Paper towel

Each group will:

1. Fill a plastic mixing cup with a cup of water. Add 5 tablespoons of salt and stir until dissolved. Add 3 tablespoons of vinegar and then stir the solution until well mixed.

2. Cut the cardboard or mat board into 4 squares measuring approximately ½ inch on each side. Soak them thoroughly in the saltwater solution. Once they are fully soaked, take them out and set them on the paper towel. They will need to be damp but not dripping with liquid.

3. Give each group a stack of five pennies. Have the students sand off the copper from one side of four of the pennies until all that is seen is the silver-colored zinc. An easy way to do this is to lay the sandpaper flat on the table, gritty side up, and energetically rub the tails-side of the pennies on the sandpaper. Remind students to do this carefully so they don't hurt their fingers. The goal is to have 4 pennies that are copper on one side and zinc on the other, and a fifth penny that is copper on both sides.

4. Start assembling the battery. Place a sanded penny copper side down, and then place a piece of damp cardboard on top of it. Repeat three times until all that is left is the unsanded penny. Place it on the top of the stack. Students will have a stack of pennies and damp cardboard with all copper sides facing down, all zinc sides facing up, except that the top penny will have copper on both sides. No pennies should touch, and no damp cardboard should touch.

5. Next, students will test their battery. Pick up the red LED and look at the leads (wires) coming out of it. One is longer than the other. Touch the longer lead to the top of the penny stack and the shorter lead to the bottom of the stack. Don't let the leads touch each other.

6. The LED should light up! If it doesn't, make sure all pennies are facing in the correct direction but not touching each other, and that the cardboards squares are damp but not dripping. Then try again. When the LED lights up, the battery is working. It sometimes takes a few minutes to reach maximum power.

7. How can students tell how much voltage their battery is producing? Take the voltmeter and touch its leads to the top and bottom of the coin battery. Record the measurement. Then use the electrical tape to attach the LED to the battery. Students can watch as the light gets fainter over time, as the cardboard dries out. Take a second measurement if the LED is still lit after one day.

8. To recharge the battery, simply soak the cardboard squares in the liquid again and put the battery back together.

9. Want to try some variations on this activity? Try making the battery with more than 5 pennies. Try a liquid solution using other liquids like lemon-lime soft drink, or mild hydrochloric acid. A blue LED requires more electricity. Try making a battery that will light up a blue LED.

10. **Answer the following questions:**
    Did the battery work with 5 pennies? If yes, what voltage did it read?

    How long did the battery stay lighted? What was the voltage on the second day?

    If students tried a different liquid, what was it, and did the LED light up?

    What was the voltage on the first and second reading? What conclusions can be drawn from this information?

    If the battery did not work, why?

11. Combine class data: For the 5-penny battery, record the voltage reading for all groups.

    Calculate the mean value (add together all values and divide by the number of values), median (middle)value and the mode (most frequent value).

Discuss your findings.

Was there a wide range of values?

Were the measurements similar?

Why do you think this occurred?

What could you do differently?

BACKGROUND INFORMATION ABOUT BATTERIES (READ AFTER LAB)

Batteries are devices that convert chemical energy into electrical energy. When two different metals are connected by an electrolyte, a chemical reaction occurs at each metal surface, called electrodes, that either releases or uses electrons. When these electrodes are connected by a wire, electrons will move from one surface to the other, creating an electric current.

Pennies that were made after 1982 have zinc cores that are plated with copper. By sanding off one face of a penny, you create a zinc electrode that can pair with the copper electrode on the face of the next penny. The cardboard soaked in salty vinegar water serves as the electrolyte between the two terminals.

Each zinc-cardboard-copper stack represents one individual cell. By stacking additional cardboards and sanded pennies, you've created a battery, which is a series of electrochemical cells. This is also called a voltaic pile, which is named after Alessandro Volta, who created the first battery in 1800 by alternating zinc and copper electrodes with sulfuric acid between them. In Volta's battery and the penny battery, an oxidation reaction occurs at the zinc electrode that releases electrons and a reduction reaction occurs at the copper electrode that uses them.

With a voltmeter, students can see that each cell can generate over 0.6 volts. The penny battery they created for this stack has four cells. A stack of three cells should generate enough voltage to light a red LED, which usually requires around 1.7 volts.

What's the Difference Between Batteries?

With a voltmeter, students can compare the storage capacity and battery life of different types of batteries. To extend this activity, provide each student group with a set of different size batteries (AAA, AA, D, etc.- **DO NOT** use car or marine batteries). Have students predict how much voltage each battery will measure, and then take readings. Do this for several days, or over two different weeks, to see how batteries lose stored energy over time.

Another experiment would be to use the battery in a battery-operated device like a flashlight, and then see how much electrical charge was lost. Students can also use their voltmeter to record before and after readings of a rechargeable battery to see if the battery is able to continue to hold the same charge over time.

LESSON 2: WHAT CAUSES BATTERY FAILURE AND CAN BATTERY FAILURE BE PREVENTED?

TASK
Explore how batteries store and release energy, and what causes thermal runaway in lithium ion batteries.

NASA NOTES
Since the X-57 gets all of its energy from electricity stored in batteries, it's important to understand how batteries work. Batteries are vulnerable to damage from temperature and pressure changes, impact (like being dropped) or punctures. NASA scientists needed to find batteries that are already commercially available, store large amounts of energy and are completely safe. Batteries that are currently on the market have a known history of operations, are built to fairly exact standards and are often cheaper that building new batteries.

When a large number of battery cells are used in combination, they are vulnerable to overheating, and can sometimes lead to fire or explosion. This phenomenon is called "thermal runaway." In the X-57, this meant packaging the batteries in specific materials and configurations so that overheating cells would be contained and the rest of the battery pack would be minimally affected. When a large number of battery cells are used in combination, they are vulnerable to overheating, and can sometimes lead to fire or explosion. This phenomenon is called "thermal runaway." In the X-57, this meant packaging the batteries in specific materials and configurations so that overheating cells would be contained and the rest of the battery pack would be minimally affected.

Since testing batteries for overheating and thermal runaway is not an activity that can be conducted safely outside of a specialized lab setting, an all-digital module was created by, and is presented with the consent of UL Xplorlabs. It focuses on how portable electric power works, how batteries can be tested, and engineering design for hover boards.

Once the digital testing is complete, investigators can select from one or more of three hands-on investigations. They also can enter into two innovation challenges to be posted on the Xplorlabs website!

Go to: https://ulxplorlabs.org/portable-electrical-power

Here is the direct link to the Teacher Guide.

LESSON 3: DIFFERENT WING, DIFFERENT LIFT

ACTIVITY 1
Understanding the Forces: Four stations with an activity for each of the forces.
https://www.nasa.gov/sites/default/files/atoms/files/four_forces_5_8.pdf

Through physical experimentation, students will learn about motions and forces, and transfer of energy as they explore the basics behind the four forces of flight. Students will be divided into four groups and witness the effects of gravity on a tennis ball, the thrust provided by an inflated balloon, the drag created by air resistance and the lift produced by their own hands in a stream of air.

ACTIVITY 2
Using Bernoulli's Principle: math-oriented lesson
https://www.teachengineering.org/lessons/view/cub_bernoulli_lesson01

Bernoulli's principle relates the pressure of a fluid to its elevation and its speed. Bernoulli's equation can be used to approximate these parameters in water, air or any fluid that has very low viscosity. Students learn about the relationships between the components of the Bernoulli equation through real-life engineering examples and practice problems.

ACTIVITY 3
A Shot Under Pressure: Using Super soaker-type devices
https://www.teachengineering.org/activities/view/cub_bernoulli_lesson01_activity1

Students use their understanding of projectile physics and fluid dynamics to find the water pressure in water guns. By measuring the range of the water jets, they are able to calculate the theoretical pressure. Students create graphs to analyze how the predicted pressure relates to the number of times they pump the water gun before shooting.

ACTIVITY 4
Build and test a wind tunnel
http://tryengineering.org/lesson-plans/wind-tunnel-testing

This lesson focuses on wind tunnel tests that engineers in many industries use to when developing products such as airplanes, cars, and even buildings. Teams of students build their own model car out of everyday products and test their design in a wind tunnel made of a fan blowing through a long cardboard box.

LESSON 4: NASA EXPEDITIONARY SKILLS FOR LIFE

Expeditions are experiences made by people who share a definite purpose and specific experiences. Although the examples in the unit focus on space exploration, they are equally applicable to aeronautics missions, or any kind of group project that requires teamwork!

To make their expeditions successful, NASA works to prepare mission team members to work together during missions. These same skills are useful in all team activities. *This module was developed in cooperation with 4-H, USDA, and the National Institute of Food and Agriculture.*

These skills are organized in four main categories:

1. **Self-Care/Team Care: Preparing for the Voyage**

   "Before you can contribute to a team, you must first be able to take responsibility for yourself. This ability includes being mentally, physically and emotionally ready to go on the voyage. Everyone has the occasional difficult day, so knowing how to support your team members is also important. This section will strengthen your ability to care for yourself and your team."

2. **Cultural Competency: Embarking on Pilgrimages**

   "Pilgrimages are searches that help people understand their personal beliefs and recognize how and why they have those beliefs. The activities in this section take you beyond your own beliefs and teach you how to understand, appreciate and value the beliefs of others. Only in creating paths that allow the team to work together can you move forward in your expeditions."

3. **Leadership/Followship: The Challenge of the Quest**

   "Lots of people like to be the leader, but leaders need a team to follow them. Different quests require different skills, which means different types of leaders are needed throughout an expedition. Understanding when to lead and when to follow, and the importance of both roles, will be explored in this section."

4. **Teamwork Communication: Launching into Orbit**

   "This section takes everything you've learned and puts it into action. To launch your expedition into orbit, everyone on the team needs to do their part. Of course, that begins with knowing what each person's part is, making sure team members are ready to perform their part and that they get it done, and dealing with any unexpected challenges that develop along the way. Launching an expedition, like teamwork, takes practice and patience."

Each of these categories has a video component, and a series of activities levelled for elementary, middle, or high school learners. Most include activities, discussion, and a form of assessment.

Learning Module Wrap-Up:

1. Return to the unanswered questions poster and discuss what is now known and still unknown. Record what students **Learned** on the K-W-L poster.
2. Retake the X-57 quiz
3. Identify any new questions or area that students would like to follow up on. Students can visit https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-109.html for the X-57 Fact Sheet.

Key to X-57 questions (most have multiple correct possible answers)

1. Why is NASA developing this technology? Reduce carbon gas emissions, reduce aircraft noise, increase energy efficiency, eliminate use of aviation fuel

2. What is unique about this aircraft? All electric, uses no gasoline, has 14 motors and propellers, has distributed electric propulsion

3. Why is it called the Maxwell? After James Clerk Maxwell who pioneered electromagnetism science, nicknamed by project team because it's all electric

4. What are the two kinds of motors, and when are they used? Two large wingtip motors to be used throughout the flight and 12 small motors mounted on front edge of wing that are used only during takeoff and landing

5. What kind of batteries will be used, and how are they tested? Many rechargeable lithium ion batteries in 50-pound battery packs. They are tested under extreme conditions like pressure, puncture and temperature change until they fail

6. How is the wing "tricked" into behaving as if it had a larger area? The air generated by the 12 small motors on the front of the wing flows above and below the wing, causing additional lift as if the wing was larger.

7. What was the first real-world test of this technology? Putting a simulated wing on top of a truck and driving it around at 80 miles per hour to see if the technology was successful.

8. What are the environmental benefits of this technology? Reduction in carbon/greenhouse gases since no fuel is burned, and reduction in noise.

9. What is "thermal runaway"? When one part of a battery overheats and spreads throughout the battery, sometimes causing fire or explosion.

10. In flight, the force we want to increase is ___lift__, and the force we want to decrease is ____ drag__. Together this increases the X-57's energy efficiency.

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