The Dayton Regional **STEM Center**
Science, Technology, Engineering and Math

NDEP
NATIONAL DEFENSE EDUCATION PROGRAM
BUILDING AMERICAN STRENGTH IN SCIENCE AND ENGINEERING

Power & Propulsion

Battery Design Challenge

Grade Level: 9th

Academic Content Area: Science, Technology, Engineering, & Mathematics

Topics: Physical Science, Science & Technology, Scientific Inquiry, Scientific Ways of Knowing, Mathematical Processes, and Data Analysis and Probability

Recommended area of co-teaching for an AFRL Engineer or Scientist

Main Problem

Design a battery for maximum voltage output by selecting the best combination of solution and metals; then consider cost-effectiveness.

Summary

Students will construct a working battery after testing various metals and solutions to determine the combination will create the highest voltage.

Big Ideas / Focus

Batteries are important form of technology for society. Batteries serve as a stored energy source. You can quickly think of multiple instances in where you are dependent on a battery (some examples are: car (electric started), calculator, iPod, hand held video game, smoke detector, or key fob). For engineers at the Air Force Research Labs b they must design batteries that will provide the most energy (criteria) but weigh the least amount (constraint). This lesson is modeled after the same engineering design process the AFRL engineers must follow; students will be problem solving, designing, and constructing a wet cell battery.

A battery is made of three main parts. The solution allows for a chemical reaction between the solution and the metals that are being used in the battery. It is also an electrolyte, which supplies ions that can move and complete the circuit, allowing electrons to flow from one metal to the other. The other two parts are the electrodes. Each electrode is made of a different metal. The two different metals in the battery create a voltage difference that allows the electrons to flow “downhill” from high concentration (negative) to low concentration (positive).

A battery works by providing electrons using the two different metals in a chemical solution. A chemical reaction between the metals and the chemical solution frees more electrons in one metal than in the other. So each metal becomes one of the battery terminals. The metal that frees more electrons develops a positive charge and the other metal develops a negative charge.

We can measure electricity in multiple ways. In this lesson we focus on voltage as a measure of the difference between electric potential between two points in an electric circuit, (Voltage = V) while current is the flow of electrons.

There are three main conditions necessary for electric current to flow. First, a conductor that allows the electrons in it to move freely (the electrons in the conductor are loosely bound). Secondly, a power source to drive the circuit, such as a battery. Lastly, a circuit must be closed with no breaks in the flow of electrons.

A conductor allows the free flow of electrons/electric charges. The electrons in a conductor are loosely bound. An insulator is a material that prevents or reduces the free flow of electrons/electric charges. The electrons in an insulator are tightly bound.

Prerequisite Knowledge

This lesson is designed as an inquiry-based lab to begin an electricity unit. Students should know the parts of the atom, specifically electrons.

A basic understanding of circuits would be helpful but not required.

Students should know how to use MS Excel to create charts and graphs.

Students should know and practice safe lab habits.

Standards Connections

Content Area: Science

Physical Sciences Standard
Students demonstrate an understanding of the composition of physical systems and the concepts and principles that describe and predict physical interactions and events in the natural world. This includes demonstrating an understanding of the structure and properties of matter, the properties of materials and objects, chemical reactions and the conservation of matter. In addition, it includes understanding the nature, transfer and conservation of energy; motion and the forces affecting motion; and the nature of waves and interactions of matter and energy. Students demonstrate an understanding of the historical perspectives, scientific approaches and emerging scientific issues associated with the physical sciences.

Grade 9 - Benchmark C: Describe the identifiable physical properties of substances (e.g., color, hardness, conductivity, density, concentration and ductility). Explain how changes in these properties can occur without changing the chemical nature of the substance.	10. Compare the conductivity of different materials and explain the role of electrons in the ability to conduct electricity.
Grade 9 - Benchmark F: Explain how energy may change form or be redistributed but the total quantity of energy is conserved.	15. Trace the transformations of energy within a system (e.g., chemical to electrical to mechanical) and recognize that energy is conserved. Show that these transformations involve the release of some thermal energy.

Science and Technology Standard
Students recognize that science and technology are interconnected and that using technology involves assessment of the benefits, risks and costs. Students should build scientific and technological knowledge, as well as the skill required to design and construct devices. In addition, they should develop the processes to solve problems and understand that problems may be solved in several ways.

Grade 9 - Benchmark A: Explain the ways in which the processes of technological design respond to the needs of society.	2. Identify a problem or need, propose designs and choose among alternative solutions for the problem. 3. Explain why a design should be continually assessed and the ideas of the design should be tested, adapted and refined.

Scientific Inquiry Standard
Students develop scientific habits of mind as they use the processes of scientific inquiry to ask valid questions and to gather and analyze information. They understand how to develop hypotheses and make predictions. They are able to reflect on scientific practices as they develop plans of action to create and evaluate a variety of conclusions. Students are also able to demonstrate the ability to communicate their findings to others.

Grade 9 - Benchmark A: Participate in and apply the processes of scientific investigation to create models and to design, conduct, evaluate and communicate the results of these investigations.	2. Research and apply appropriate safety precautions when designing and conducting scientific investigations (e.g., OSHA, Material Safety Data Sheets [MSDS], eyewash, goggles and ventilation). 5. Develop oral and written presentations using clear language, accurate data, appropriate graphs, tables, maps and available technology. 6. Draw logical conclusions based on scientific knowledge and evidence from investigations.

Scientific Ways of Knowing Standard
Students realize that the current body of scientific knowledge must be based on evidence, be predictive, logical, subject to modification and limited to the natural world. This includes demonstrating an understanding that scientific knowledge grows and advances as new evidence is discovered to support or modify existing theories, as well as to encourage the development of new theories. Students are able to reflect on ethical scientific practices and demonstrate an understanding of how the current body of scientific knowledge reflects the historical and cultural contributions of women and men who provide us with a more reliable and comprehensive understanding of the natural world.

Grade 9 - Benchmark C: Describe the ethical practices and guidelines in which science operates.	2. Illustrate that the methods and procedures used to obtain evidence must be clearly reported to enhance opportunities for further investigations.
Grade 9 - Benchmark D: Recognize that scientific literacy is part of being a knowledgeable citizen.	9. Investigate how the knowledge, skills and interests learned in science classes apply to the careers students plan to pursue.

Content Area: Math

Data Analysis and Probability Standard
Students pose questions and collect, organize, represent, interpret and analyze data to answer those questions. Students develop and evaluate inferences, predictions and arguments that are based on data.

Grade 9 - Benchmark F: Construct convincing arguments based on analysis of data and interpretation of graphs.	1. Describe measures of center and the range verbally, graphically and algebraically. 6. Interpret the relationship between two variables using multiple graphical displays and statistical measures; e.g., scatterplots, parallel box-and-whisker plots, and measures of center and spread.

Preparation for activity

Make Photocopies of each of the following documents:

- Battery Pre/Post Test (2 copies/student)
- Battery Design Challenge Lab Packet (includes rubrics)
- How to use a Voltmeter (Appendix A)
- Cost Analysis Information Bank (Appendix B)

Critical Vocabulary

Anode - negatively charged terminal of a battery that is supplying current

Cathode - positively charged terminal of a battery that is supplying current

Circuit - a closed path followed or capable of being followed by an electric current

Conductor - a substance or medium that allows electric current to flow

Current - the flow of electrons (symbol = I)

Electrode - a conductor through which electricity enters of leaves

Electrolyte - an electrolyte is any substance containing free ions that behaves as an electrically conductive medium

Insulator - substance or medium that does not allow electric current to flow

Ion - an electrically charged atom or group of atoms; an ion has acquired its charge by losing or gaining one or more electrons

Load - A device or the resistance of a device to which power is delivered

Surface Area - the sum of the areas of the faces of a solid figure

Voltage - a measure of the difference between electric potential between two points in space, a material or electric circuit (symbol = V)

Wet Cell Battery - a device containing a solution that converts chemical energy into electrical energy

Timeframe

Day	Time Allotment	Activities
1	10 minutes 20 minutes 20 minutes	1. Pre-Test 2. Have a variety of battery-operated items, as well as fruit, pop, solutions, metals, and batteries out for students to examine. What do all of these things have in common? 3. Divide students into teams of 4 and give each team their Battery Design Challenge Packet. The team of four needs to come up with their corporation name and then subdivide their team into two specialty groups—metallurgy and solutions. Once the team had subdivided, they may begin to examine their test materials and develop a hypothesis to test on either which solution or which metal combination respectively will provide the best voltage. Hypothesis should be written today.
2	50 minutes	Student research teams will work with either the metals or the solutions depending on their assignment. Emphasize that student teams (of 2) need to test and record data carefully in order to provide information to the other half of their team. (Data should first be recorded in a science notebook and then can be recorded in an Excel spreadsheet.)
3	50 minutes	Student company teams (metallurgy team and solution team) need to come together and share their respective data. Students will hypothesize on the best combination of metals and solution to use to provide the highest voltage. Students then will test their hypothesis of which combination will provide the highest voltage. Students can rework/retest data as needed and may begin to work on their team proposal.
4	30 minutes 20 minutes	Teacher should complete a mini-lesson on batteries including components and basic function. Students can watch: “How It’s Made: Alkaline Batteries” http://www.youtube.com/watch?v=IMedX5i-4aM Students will then apply the information to their system and develop an explanation of how their battery works including graphic/visual diagrams. Teacher will discuss upcoming proposal guidelines and deadline.
5	50 minutes	Team lab report/business proposal preparation day. Students will work in their teams to prepare their typed proposals and oral presentations.
6	30 minutes	Battery team oral presentations to the class.

Materials & Equipment

General Materials	Alligator Clips Digital Scales Calculator LED bulbs (Optional for extension activities) Copper Wire
Solutions Team	Voltmeter / Multimeter 150 mL beakers Copper & Zinc metal pH strips Masking tape Solutions: Water, Lemon Juice, Grape Fruit Juice, The Works Toilet Bowl Cleaner, Vinegar, Energy Drinks, Gatorade, etc.
Metallurgy Team	Metals: copper, zinc, aluminum, carbon, lead, nickel, magnesium Voltmeter / Multimeter 150 mL beaker Vinegar Masking Tape
Surface Area Tests *(extension)*	Metric Ruler Micrometer (for surface area measurements) Calculator Various sizes/surface area samples of Copper and Zinc (or whichever metals the teams choose) Vinegar or other Test Solution that the team chooses Voltmeter / Multimeter 150 mL Beaker

Safety & Disposal

Goggles & lab aprons should be worn at all times when working with the metals and solutions.

MSDS should be available for all students to review prior to working with the solutions

Eyewash and safety shower should be available for students to access.

Be careful with metals as some may have sharp edges.

Be sure to wash hands prior to leaving the lab each day.

Teachers Note: Depending on the solutions provided, students will need specific instructions for disposal and cleanup.

Do not allow students to mix solutions—all substances must remain pure.

Pre-Activity Discussion

Be sure that students know how to correctly work the voltmeter or multimeter (refer to instructional tips).

Discuss safety (goggles and aprons at all times) and proper disposal of solutions.

What is a battery and how does it work? Having students brainstorming these ideas prior to the start of the lab will help them to focus on what they are creating and how they might construct it.

Teacher Instructions:

Day 1:

Pre-Test: Administer Pre-Test (10 minutes), grade and use data to group students, unless you plan to use random grouping.

Introduction Brain-think on Batteries: Have a variety of battery-operated items, different types of batteries (if possible an integrated power box) as well as materials that can be used to build batteries (fruits, soda-pop, solutions, and metals) out for students to examine. What do all of these things have in common? Discuss as a class.

Organize students into their lab teams either randomly or predetermined by the pre-test results. Hand out the Battery Design Challenge Packet.

Specialty Teams: Students need to be grouped and have the opportunity to explore the materials that they will be working with—they should develop hypotheses for tomorrow's tests. They also should discuss possible variables in their lab design. Teach students how to use the voltmeters or multimeters today. Give each group 1 multimeter and a battery and demonstrate how to measure voltage. They need to be comfortable with this tool, so that they will have success in the lab tomorrow. (Having students use an AA battery allows them to see the voltage relationship between the typical batteries that they are used to using and the batteries that they will be making.)

Day 2: Specialty Team Testing Day: Students will work in their specialty team (metallurgy or solutions) to determine which metal combination or which solution will provide the highest voltage. Students should wear goggles and lab aprons at all times. Hand out the Metallurgy Team Design Sheet and the Solutions Team Design Sheet for students to use as they complete their tests. If students are familiar with inquiry design, than perhaps you do not need to provide them with these "help" sheets. Student teams need to create data tables to report results to their peers using the computer.

Day 3: Data Share and Experiment Day: Solution Teams and Metallurgy teams come together to share data and test which combination will create the highest voltage. All students should wear goggles and lab aprons throughout the experimentation. Constantly monitor students as they work. Expand and strengthen student understanding by orally quizzing individuals on their process and analysis of results.

Day 4: Mini lesson on batteries/electricity by teacher and watch the video *"How It's Made: Alkaline Batteries".* Student teams will apply information to their system and begin to diagram and explain how their battery works. Students should be able to diagram all components and explain their role in the battery design.

OPTIONAL HOMEWORK: Hand out Battery Proposal Guidelines. Set appropriate deadline. Tell students to put this deadline in the appropriate area of the Day 4 task list.

Day 5: Team work day to prepare written and oral proposal for the City Manager and City Council members addressing the needs that the battery designs should meet: provide as much voltage as possible for the least amount of money. Additional desirable criteria include portability, lightweight, and safe/green.

Discuss with students what it means for a battery to provide maximum voltage, be portable, lightweight, safe/green, and cost effective. Explain how science and engineering extend to the business sector and human applications.

Day 6: Battery Design Presentation Day using the STEM Battery Presentation Rubric and the STEM Battery Design Specification Rubric. Student teams will turn in Written Battery Proposals to be graded with the Formal Battery Proposal Document Rubric.

Homework: Have students create a formal battery proposal using the Formal Battery Proposal Document Rubric provided after Lesson 4 in their lab packet.

Background Information

A common misconception about batteries is that they "create" electrons. In reality, the electrons in the metals are redistributed during a chemical reaction between the solution and the metals strips.

The solution allows for a chemical reaction between the solution and the metals that are being used in the battery. It is also an electrolyte allowing for the free electrons to move from one metal to the other to complete the circuit.

The two different metals in the battery create a voltage difference that allows the electrons to flow "downhill" from high concentration (negative) to low concentration (positive).

So each metal becomes one of the battery terminals. The metal that frees more electrons develops a positive charge and the other metal develops a negative charge.

Instructional Tips

To teach how to use the voltmeter or multimeter, you may want to have students obtain their first set of materials to test on Day 2 and then go through the process as a class. A document camera is ideal so that all students can see the equipment and hook-up with ease. There is also a provided hand out to help students (Appendix A). If students get a negative read-out, they need to switch their wire connections.

To reduce the amount of solutions being consumed, have solutions clearly labeled in beakers for student groups to use as they test the different solutions on Day 2.

Students sometimes have a hard time identifying the variables in their experiments. Some examples are; amount of solution, the surface area of the metals, and the distance the metals were from each other in the solution.

Encourage students to complete research and work on their proposal outside of class for homework, so that their class time can be used to work as a team.

Encourage students to continually review the appropriate rubric as they work through the process.

Some students will measure a voltage and still not see that they have created a battery. Offer additional scaffolding to these individuals. This can be accomplished by going through the parts of a battery and identifying them in their own experimental design.

Masking tape stretched across the top of the beaker works well to hold the metal pieces in place during the tests.

The “Cost-Analysis Information Bank” was based on current market value (2009) or price of materials from the store. Students had to practice metric conversions to go from English to Metric. The cost is relatively small but was a good experience to show the connection between actual cost and sales prices.

For ease of use in the class demonstrations, a rudimentary stand can be created and used to test various metals and solutions in front of the class for all students to see.

Assignment of Student Roles and Responsibilities

Students will assume different roles:

Member	Role Name	Brief Description
1 and 2	Metallurgy Specialist	The Metallurgy Specialists will be in charge of testing the various metals, in a given solution, to determine which metal combination will produce the greatest difference in voltage.
3 and 4	Solutions Specialist	The Solutions Specialists will be in charge of testing the various provided solutions, given a set of metals, to determine which solution will serve as the best electrolyte and react with the metals.

Student Instructions

Scenario:

Your city needs an integrated power box that can operate a variety of electronic equipment (i.e. phone, walkie-talkie, sensor devices, GPS, etc.). Each of these devices, when powered alone, requires different amounts of voltage. Your firm has decided to bid on this project, so you and your fellow engineers must design a battery that will provide as much voltage as possible for the least amount of money. Additional desirable criteria include portability, lightweight, and safe/green.

Lab Design:

You will work in lab teams of four; two members will serve as metallurgy specialists and two members will serve as solutions specialists.

DAY	TASKS
Day 1: Introduction and Roles	Brainstorm on Batteries. Meet with lab teams and divide into twp specialty teams to research which materials will work the best for their battery design. (Metallurgy specialist & Solutions specialist) Students can research using computers/text and develop hypothesis to be tested.
Day 2: Research	Students work in specialty team (metallurgy or solutions) to determine which metal combination or which solution will provide the highest voltage.

Student teams need to create data tables to report results to their peers.

Day 3: Data Share and Experiment	Solution teams and Metallurgy teams come together to share data and test which combination will provide the highest voltage.
Day 4: A Look at Batteries	Mini lesson on batteries by teacher. Student teams will apply information to their system and begin to diagram and explain how their battery works. Use rubric to guide your design.
Day 5: Proposal Day	Team work day to prepare written and oral proposal for the City Manager and City Council members addressing the needs that the battery designs should meet: battery should provide as much voltage as possible for the least amount of money. Remember that additional desirable criteria include portability, lightweight, and safe/green. Use rubric to guide your presentation.
Day 6: Presentation	Battery Design Presentation Day using the STEM Battery Presentation Rubric & STEM Battery Design Specification Rubric. Homework Option: Turn in Written Battery Proposals (Teacher will grade using the Formal Battery Proposal Document Rubric)

Metallurgy Team Analysis
Lab Analysis Information:

You and your fellow specialist are in charge of determining which metal pair will work the best by providing the highest voltage using the given solution. You will need to choose a minimum of 4 metals to test in a variety of combinations. You will complete the metals data table to gather some initial data about the materials. From there you need to create a metal combination chart to show which combinations of metals you have tested and the voltage that was produced.

Metal Combinations:
Create a data table for your combinations and the voltage that each produced.

Metal Justification:
Provide written justification for which metal/s that you will choose to present to the other half of your team for your battery design.

Solutions Team Analysis
Lab Analysis Information:

You and your fellow specialist are in charge of determining which solution will work the best by providing the highest voltage using the given metals. You will need to choose a minimum of 4 solutions to test (You are not permitted to mix solutions). You will complete the solutions data table to gather some initial data about the materials.

Solutions:
Create a data table for your solutions and the voltage that each produced.

Solution Justification:
Provide written justification for which solution you will choose to present to the other half of your team for your battery design.

Battery Proposal Guidelines

Here are some key points to consider for your presentation and proposal:

- What voltage does your cell provide?
- How much would the solution cost for a single cell in your battery?
- How much would the metals cost for a single cell in your battery?
- What is the total cost for your battery?
- If your battery needs to provide 12.6 volts of electricity, how many cells would you need?
- How does Electric Potential Difference come into play in your battery design?
- Explain how your design works. Explain electrochemical cells.
- How could you package your battery for use in the field? *(portable & lightweight)*
- What safety concerns need to be taken into consideration with your battery? *(safe/green)*

Why should the City Council, City Manager and Mayor choose your team's design? Convince them! Be prepared to defend your design and process.

Formative Assessments

Students will be administered a pre- and post-test.

Students will be formally graded on battery design, a presentation, and an optional formal proposal paper.

Battery Design Rubric

CATEGORY	4	3	2	1
Efficient	Battery design is efficient and operates at a high voltage. Creates a voltage reading of over 1.01 mV	Battery design creates a voltage between .91 mV and 1.0 mV.	Battery design creates a voltage between .81 mV and .90mV	Battery design creates a voltage less than .80 mV
Portable	The battery design is small and easily moved as part of the integrated power box. Packaging is well designed and functional.	The battery design is portable but not as compact, causing the power box to be larger. Package design is functional but not well designed.	The battery design is not very portable. Design and function need to be improved for long term operation by user.	The battery design is not portable; the power box is too large and not functional due to packaging design.

Lightweight	Package design is lightweight and able to be carried easily as part of an integrated power box. Weight is not a concern for the user.	Package design is lightweight but not able to be carried easily as part of an integrated power box. Weight becomes a concern of the user over extended time.	Package design is not lightweight. The battery causes the integrated power box to be too heavy for extended operation by the user.	Package design is heavy and not practical for an integrated power box.
Safe	Battery design is safe for consumer and the environment. No known environmental impact or disposal concerns.	Battery design is safe for the consumer but not the environment. Long term disposal concerns and major environmental impact identified.	Battery design has significant threats to consumer and major environmental impact.	Battery design is not safe and harmful to the environment. Risk is not worth the energy produced.
Cost Effective	Battery design is cost effective maximizing the cost of materials per voltage created. Create the highest voltage for the least amount of money.	Battery design has a relatively low cost but changes could be made to decrease the cost rather easily.	Battery design was expensive for the voltage created.	Battery design is not cost effective. No relation was made between materials used and cost. Product is too expensive for power output.

Formal Battery Proposal Document Rubric

CATEGORY	4	3	2	1
Materials	All materials and setup used in the experiment are clearly and accurately described.	Almost all materials and the setup used in the experiment are clearly and accurately described.	Most of the materials and the setup used in the experiment are accurately described.	Many materials are described inaccurately OR are not described at all.
Procedures	Procedures are listed in clear steps. Each step is numbered and is a complete sentence.	Procedures are listed in a logical order, but steps are not numbered and/or are not in complete sentences.	Procedures are listed but are not in a logical order or are difficult to follow.	Procedures do not accurately list the steps of the experiment.
Replicability	Procedures appear to be replicable. Steps are outlined sequentially and are adequately detailed.	Procedures appear to be replicable. Steps are outlined and are adequately detailed.	All steps are outlined, but there is not enough detail to replicate procedures.	Several steps are not outlined AND there is not enough detail to replicate procedures.

Variables	All variables are clearly described with all relevant details.	All variables are clearly described with most relevant details.	Most variables are clearly described with most relevant details.	Variables are not described OR the majority lack sufficient detail.
Scientific Concepts	Report illustrates an accurate and thorough understanding of scientific concepts underlying the lab.	Report illustrates an accurate understanding of most scientific concepts underlying the lab.	Report illustrates a limited understanding of scientific concepts underlying the lab.	Report illustrates inaccurate understanding of scientific concepts underlying the lab.
Analysis	The relationship between the variables is discussed and trends/patterns logically analyzed. Predictions are made about what might happen if part of the lab were changed or how the experimental design could be changed.	The relationship between the variables is discussed and trends/patterns logically analyzed.	The relationship between the variables is discussed but no patterns, trends or predictions are made based on the data.	The relationship between the variables is not discussed.
Summary	Summary describes the skills learned, the information learned and some future applications to real life situations.	Summary describes the information learned and a possible application to a real life situation.	Summary describes the information learned.	No summary is written.
Drawings/ Diagrams	Clear, accurate diagrams are included and make the experiment easier to understand. Diagrams are labeled neatly and accurately.	Diagrams are included and are labeled neatly and accurately.	Diagrams are included and are labeled.	Needed diagrams are missing OR are missing important labels.
Data	Professional looking and accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled.	Accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled.	Accurate representation of data in written form, but no graphs or tables are presented.	Data is not shown OR is inaccurate.

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Presentation Rubric

CATEGORY	4	3	2	1
Group Work	The group functioned exceptionally well. All members listened to, shared with and supported the efforts of others. The group (all members) was almost always on task!	The group functioned pretty well. Most members listened to, shared with and supported the efforts of others. The group (all members) was almost always on task!	The group functioned fairly well but was dominated by one or two members. The group (all members) was almost always on task!	Some members of the group were often off task AND/OR were overtly disrespectful to others in the group AND/OR were typically disregarded by other group members.
Research	Group researched the subject and integrated 3 or more "tidbits" from their research into their newscast.	Group researched the subject and integrated 2 "tidbits" from their research into their newscast.	Group researched the subject and integrated 1 "tidbit" from their research into their newscast.	Either no research was done or it was not clear that the group used it in the newscast.
Accuracy of Facts	All supportive facts are reported accurately (3 of 3).	Almost all facts are reported accurately (2 of 3).	One fact is reported accurately.	No facts are reported accurately OR no facts were reported.
Presentation of Content	Presentation accurately portrays the function of the battery and all battery components are discussed. Cohesive presentation.	Presentation accurately portrays the function of the battery but not all battery components are discussed.	Presentation either accurately portrays the function or discusses the battery components, but does not discuss both.	Presentation of content is choppy and no clear connection is made between battery components and function.
Speaks clearly	Speaks clearly and distinctly all of the time and mispronounces no words.	Speaks clearly and distinctly all of the time but mispronounces 1 or more words.	Speaks clearly and distinctly most of the time and mispronounces no words.	Does NOT speak clearly and distinctly most of the time AND/OR mis-pronounces more than 1word
Graphics	Graphics include some original material and are clearly related to the material being presented.	Graphics are clearly related to the material being presented, but none are original.	Graphics include some original material but are only somewhat related to the material being presented.	Graphics are not related to the material being presented.

Post-Activity Discussion

Discuss the components of the battery and their functions as well as what is needed for an electric current to flow.

Attention should be given to the different designs that were developed and examined to determine what gives the optimal voltage.

Variables between groups could also be discussed to determine their impact on the experimental results.

Pre-Test / Post-Test

1. **What is a conductor? What is an insulator?** *A conductor allows the free flow of electrons/electric charges. The electrons in a conductor are loosely bound. An insulator is a material that prevents or reduces the free flow of electrons/electric charges. The electrons in an insulator are tightly bound.*
2. **How does a battery provide electrons?** *A battery provides electrons using two different metals in a chemical solution. A chemical reaction between the metals and the chemical solution frees more electrons in one metal than in the other. So each metal becomes one of the battery terminals. The metal that frees more electrons develops a positive charge and the other metal develops a negative charge.*
3. **What is an electrolyte solution?** *An electrolyte is any substance containing free ions that behaves as an electrically conductive medium. The solution allows for a chemical reaction between the solution and the metals that are being used in the battery. It is also an electrolyte, which supplies ions that can move and complete the circuit, allowing electrons to flow from one metal to the other.*
4. **What is the difference between voltage and current?** *Voltage is a measure of the difference between electric potential between two points in an electric circuit, (Voltage = V) while current is the flow of electrons (current = I). Voltage can be thought of as something that pushes the electrons into motion (another name for it is electromotive force) and current can be thought of as how fast the electrons are moving.*
5. **What are the 3 main conditions for an electric current to flow?**
   1. *A conductor that will allow the electrons in it to move freely (the electrons in the conductor are loosely bound).*
   2. *A power source to drive the circuit, such as a battery.*
   3. *The circuit must be closed with no breaks in the flow of electrons.*

Pre-Test / Post-Test Rubric

CATEGORY	3 Points	2 Points	1 Point
1. What is a conductor? What is an insulator?	Both a conductor and insulator are fully explained and a clear understanding of each is apparent.	Only the conductor or the insulator is explained; not both.	Neither the conductor nor insulator is explained: Lack of understanding is apparent.

2. How does a battery provide electrons?	Response clearly and accurately discusses the role of the metals, solutions and electrons in explaining how the battery provides electrons.	Response does not clearly discuss the role of the solutions, metals and/or electrons. Mention could be made of parts but no relation is made between the components. Lack of understanding is apparent.	Response does not demonstrate how a battery provides electrons.
3. What is an electrolyte solution?	Electrolyte solution is clearly defined; Understanding is apparent.		Electrolyte solution is not defined correctly.
4. What is the difference between voltage and current?	Both voltage and current are accurately defined and then contrasted to clearly demonstrate the difference between the two.	Either voltage or current is accurately defined but no difference is distinguished between the two.	Neither current nor voltage are accurately defined or explained. No difference is articulated.
5. What are the 3 main conditions for an electric current to flow?	All three conditions are clearly/accurately explained and related to each other.	Only two of the conditions are accurately explained.	Only one condition is explained.

Technology Connection

The **ADISC** Model created by ITEL:

Integration Model	**Application Description**
Technology that supports students and teachers in **dealing effectively with data**, including data management, manipulation, and display	MS Excel MS word
Technology that supports students and teachers in conducting **inquiry**, including the effective use of Internet research methods	View "How It's Made: Alkaline Batteries": available at YouTube or iTunes Document camera to aid in the instruction of the use of the voltmeters and multimeters (ELMO and Samsung Both manufacture document cameras) Multimeter or voltmeter to measure voltage output http://www.youtube.com/watch?v=W1czBcnX1Ww: robotic dog video clip

Technology that supports students and teachers in **simulating** real world phenomena including the modeling of physical, social, economic, and mathematical relationships	Websites that provide background and diagrams on how batteries work: http://electronics.howstuffworks.com/battery.htm http://www.energizer.com/learning-center/Pages/how-batteries-work.aspx http://www.rayovac.com/wizard/battery_howwork.htm
Technology that supports students and teachers in **communicating and collaborating** including the effective use of multimedia tools and online collaboration	MS Word MS PowerPoint Teleconferencing or videoconferencing equipment

Interdisciplinary Connection

Math – Students can complete surface area calculations as well as calculate voltage and current as an extension of the activity. Students will also use basic math to complete cost analysis of the materials used to construct their battery.

Home Connection

Students can identify as many different types of batteries that they can find within their home. What are their uses? What is each battery's typical life span? How are the sizes of the batteries varied for their function? Is bigger better? How is each battery packaged and what types of materials are used to construct the package?

Differentiated Instruction

Process – Students can be grouped based on their pre-test results. Mixed ability groups work well focusing on student interests as well as abilities.

Product – The product will be varied from group to group—there is no one correct answer to how students will solve the problem. Depending on the grouping there could be possibly different expectations or adapted rubrics for groups.

In day two: those that need less direction can develop their own organization schemes and those groups that need more direction can use the provided sheets.

Students having difficulty creating a data table may have a teacher constructed one. Below are two examples:

Students can also be asked to write an individual reflection and improvement should be seen in the post-test that all students will take.

Content – For higher ability students begin challenging them with figuring out relationship of electrode surface area to voltage.

Students can experiment with how to increase their voltage output by wiring batteries in series or parallel circuits.

Students can attempt to power different items to see how much voltage is needed. This is a qualitative analysis. (A potential example is flashlights with varying strength of light bulbs.)

Content - This activity can be easily leveled for students. For higher ability students begin challenging them with figuring out surface area relations to voltage provided. Challenge students to try to figure out how to increase their voltage by wiring batteries in series or parallel circuits. Have students try to attach different loads to their circuits/batteries: Why, if there is a high enough voltage, do the loads not always function?

Sample Metals Data Table

Metals	Description	Mass	Surface Area	Voltage

Sample Solutions Data Table

Solution	Physical Description	Volume	Mass	pH	Voltage

Lab Materials
Most of the lab equipment used in this lab can be found in a typical high school classroom. Be sure to have voltmeters (need to read millivolts) or multi meters for each team.

Presentation
Have computers available for students to complete data analysis, their formal battery proposal (lab write-up) and team presentation.

Extension

From this lesson, students can wire their batteries into series and parallel circuits to compare differences in voltage and/or current.

Components of a circuit can be taught and different loads can be used to show differences in the electrical draw of items.

Calculations can be completed with voltage and current.

Challenge students to think about how a rechargeable battery works.

Career Connection

This activity can be related to electrical and/or chemical engineering.

The design of the battery is an important task in today's society as we try to stretch the limits of our current technologies. Batteries are going to have to get smaller and even more efficient as our society becomes more mobile and technology dependent.

There are also connections to battery-operated cars that could be explored as an extension to the lesson.

The environmental engineer's role can also be addressed within the lesson as students must take their design from cradle to grave to ensure it will be safe not only during use, but in its disposal once it has been discarded.

The airforce has a large interest in battery technology. A common challenge many engineers face in batteries is the power/size ratio.

Engineers working on small unmanned aircraft (UAVs) must always keep in mind that the power source to launch and fly the UAV must be contained in the unit. Some UAV's also have a battery charger unit that is separate from the UAV and its main battery. This again, is more payload the soldier must carry.

Engineers developing robots are concerned with battery weight because the battery is part of the robot. The heavier the battery, the heavier the robot and the more power is required for mobility. A current robotics project is the robotic dog which has been designed to carry supplies (http://www.youtube.com/watch?v=W1czBcnX1Ww).

There is a lot of current research on air lithium batteries, imagine the impact of not having to carry the electrolyte needed for the battery because it is readily available air.

You can arrange for an air force engineer or scientist to come in and talk to your students about one of these cutting edge technologies. If a visit is not an option arrange for a teleconference or videoconference.

Additional Resources

Resources	Purpose and Application
http://www.newi.ac.uk/buckleyc/electric.htm	Notes for first year BA Primary Education students at the North East Wales Institute, Wrexham, by Clive Buckley, Ph.D.
Cynmar Corporation www.cynmar.com Fisher Scientific www.fisheredu.com Sargent-Welch www.sargentwelch.com	Voltmeters can be purchased as well as metals and test chemicals from these companies.
Radio Shack	Great place to pick up LED lights and voltmeters, copper wire and alligator clips, all of which are relatively inexpensive.
http://www.youtube.com/watch?v=W1czBcnX1Ww	You tube video on the robotic dog, a military prototype that carries its own battery source. This prototype is designed for carrying a payload.

Credits

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Emily Bowers – Contributing author
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Norma Howell – Contributing author, Editor
Sandra Preiss – Editor

Teacher Reflections

- **Were students focused and on task throughout the lesson?** *Yes.*
- **How did students demonstrate that they were actively learning?** *Through asking questions about batteries, writing down data, discussion of data, and giving presentations students we actively learning.*
- **Did you find it necessary to make any adjustments during the lesson?** *Yes.*
- **What were they?** *It took longer on each project. I had to work closely with groups. I poured the solution to reduce waste.*
- **Did the materials that the students were using affect classroom behavior or management?** *Students wanted to play with the voltmeter.*
- **What were some of the problems students encountered when using the …?**
- **Are there better items that can be used next time?** *Possibly make the liquid into a paste and build a dry cell battery instead.*
- **Which ones worked particularly well?**
- **If not, what improvements could be made the next time this lesson is used?**
- **Were the students led too much in the lesson or did they need more guidance?**
- **Did the students learn what they were supposed to learn?**
- **How do you know?**

Additional Comments

The unit was well thought out.

Be careful with liquids especially in regards to special needs individuals.

Students needed help with measuring and pouring.

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Test

1. What is a conductor?

   What is an insulator?

2. How does a battery provide electrons?

3. What is an electrolyte solution?

4. What is the difference between voltage and current?

5. What are the 3 main conditions for an electric current to flow?

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BATTERY DESIGN LAB PACKET

Scenario:

Your city needs an integrated power box that can operate a variety of electronic equipment (i.e. phone, walkie-talkie, sensor devices, GPS, etc.). Each of these devices, when powered alone, requires different amounts of voltage. Your firm has decided to bid on this project, so you and your fellow engineers must design a battery that will provide as much voltage as possible for the least amount of money. Additional desirable criteria include portability, lightweight, and safe/green.

Lab Design:

You will work in lab teams of four; two members will serve as metallurgy specialists and two members will serve as solutions specialists.

Definitions:

Anode - negatively charged terminal of a battery that is supplying current

Cathode - positively charged terminal of a battery that is supplying current

Circuit - a closed path followed or capable of being followed by an electric current

Conductor - a substance or medium that allows electric current to flow

Current - the flow of electrons (symbol = I)

Electrode - a conductor through which electricity enters of leaves

Electrolyte - an electrolyte is any substance containing free ions that behaves as an electrically conductive medium

Insulator - substance or medium that does not allow electric current to flow

Ion - an electrically charged atom or group of atoms; an ion has acquired its charge by losing or gaining one or more electrons

Load - A device or the resistance of a device to which power is delivered

Surface Area - the sum of the areas of the faces of a solid figure

Voltage - a measure of the difference between electric potential between two points in space, a material or electric circuit (symbol = V)

Wet Cell Battery - a device containing a solution that converts chemical energy into electrical energy

Three main conditions necessary for electric current to flow:

1. A conductor that allows the electrons in it to move freely (the electrons in the conductor are loosely bound).
2. A power source to drive the circuit, such as a battery.
3. A circuit must be closed with no breaks in the flow of electrons.

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BATTERY DESIGN LAB

Day 1: Introduction and Roles

TASKS	COMPLETION
Brainstorm on Batteries.	
Meet with lab teams and divide into twp specialty teams to research which materials will work the best for their battery design. (Metallurgy specialist & Solutions specialist)	
Students can research using computers/text and develop hypothesis to be tested.	

Battery Brainstorm

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Assign Roles

Role Name & Team Member	Brief Description
Metallurgy Specialist Name ________________________ Name ________________________	The Metallurgy Specialists will be in charge of testing the various metals, in a given solution, to determine which metal combination will produce the greatest difference in voltage.
Solutions Specialist Name ________________________ Name ________________________	The Solutions Specialists will be in charge of testing the various provided solutions, given a set of metals, to determine which solution will serve as the best electrolyte and react with the metals.

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BATTERY DESIGN LAB

DAY 2: Research

TASKS	**COMPLETION**
Students work in specialty team (metallurgy or solutions) to determine which metal combination or which solution will provide the highest voltage.	
Student teams need to create data tables to report results to their peers. (Use guidelines below)	

****Make sure to share your findings with the other team so they have the data needed for the Lab Proposal Assignment****

Metallurgy Team

1. Lab Analysis Information:
   You and your fellow specialist are in charge of determining which metal pair will work the best by providing the highest voltage using the given solution. You will need to choose a minimum of 4 metals to test in a variety of combinations. You will complete the metals data table to gather some initial data about the materials. From there you need to create a metal combination chart to show which combinations of metals you have tested and the voltage that was produced.

2. Metal Combinations:
   Create a data table for your combinations and the voltage that each produced.

3. Metal Justification:
   Provide written justification for which metal/s you will choose to present to the other half of your team for your battery design.

Solutions Team Analysis

1. Lab Analysis Information:
   You and your fellow specialist are in charge of determining which solution will work the best by providing the highest voltage using the given metals. You will need to choose a minimum of 4 solutions to test (You are not permitted to mix solutions). You will complete a solutions data table to gather some initial data about the materials.

2. Solution Combinations:
   Create a data table for your solutions and the voltage that each produced.

3. Solution Justification:
   Provide written justification for which solution you will choose to present to the other half of your team for your battery design.

****Make sure to share your findings with the other team so they have the data needed for the Lab Proposal Assignment****

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BATTERY DESIGN LAB

Day 3: Data Share and Experiment

TASKS	COMPLETION
Solution teams and Metallurgy teams come together to share data and test which combination will provide the highest voltage.	

Test Results:

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BATTERY DESIGN LAB

Day 4: A Look at Batteries

TASKS	**COMPLETION**
Homework due: ___________________________ Formal Battery Proposal Document (Use rubric to guide your proposal)	
Mini lesson on batteries by teacher.	
Student teams will apply information to their system and begin to diagram and explain how their battery works.	
Use rubric to guide your design.	

Battery Lesson Notes:

Draw a diagram of your design: (make sure to label it accurately)

Here are some key points to think of for your presentation and proposal that you should start considering!

- What voltage does your cell provide?
- How much would the solution cost for a single cell in your battery?
- How much would the metals cost for a single cell in your battery?
- What is the total cost for your battery?
- If your battery needs to provide 12.6 volts of electricity, how many cells would you need?
- How does Electric Potential Difference come into play in your battery design?
- Explain how your design works. Explain electrochemical cells.
- How could you package your battery for use in the field?

- What safety concerns need to be taken into consideration with your battery?

Battery Design Rubric

CATEGORY	4	3	2	1
Efficient	Battery design is efficient and operates at a high voltage. Creates a voltage reading of over 1.01 mV	Battery design creates a voltage between .91 mV and 1.0 mV.	Battery design creates a voltage between .81 mV and .90mV	Battery design creates a voltage less than .80 mV
Portable	The battery design is small and easily moved as part of the integrated power box. Packaging is well designed and functional.	The battery design is portable but not as compact, causing the power box to be larger. Package design is functional but not well designed.	The battery design is not very portable. Design and function need to be improved for long term operation by user.	The battery design is not portable; the power box is too large and not functional due to packaging design.
Lightweight	Package design is lightweight and able to be carried easily as part of an integrated power box. Weight is not a concern for the user.	Package design is lightweight but not able to be carried easily as part of an integrated power box. Weight becomes a concern of the user over extended time.	Package design is not lightweight. The battery causes the integrated power box to be too heavy for extended operation by the user.	Package design is heavy and not practical for an integrated power box.
Safe	Battery design is safe for consumer and the environment. No known environmental impact or disposal concerns.	Battery design is safe for the consumer but not the environment. Long term disposal concerns and major environmental impact identified.	Battery design has significant threats to consumer and major environmental impact.	Battery design is not safe and harmful to the environment. Risk is not worth the energy produced.
Cost Effective	Battery design is cost effective maximizing the cost of materials per voltage created. Create the highest voltage for the least amount of money.	Battery design has a relatively low cost but changes could be made to decrease the cost rather easily.	Battery design was expensive for the voltage created.	Battery design is not cost effective. No relation was made between materials used and cost. Product is too expensive for power output.

Formal Battery Proposal Document Rubric

CATEGORY	4	3	2	1
Materials	All materials and setup used in the experiment are clearly and accurately described.	Almost all materials and the setup used in the experiment are clearly and accurately described.	Most of the materials and the setup used in the experiment are accurately described.	Many materials are described inaccurately OR are not described at all.
Procedures	Procedures are listed in clear steps. Each step is numbered and is a complete sentence.	Procedures are listed in a logical order, but steps are not numbered and/or are not in complete sentences.	Procedures are listed but are not in a logical order or are difficult to follow.	Procedures do not accurately list the steps of the experiment.
Replicability	Procedures appear to be replicable. Steps are outlined sequentially and are adequately detailed.	Procedures appear to be replicable. Steps are outlined and are adequately detailed.	All steps are outlined, but there is not enough detail to replicate procedures.	Several steps are not outlined AND there is not enough detail to replicate procedures.
Variables	All variables are clearly described with all relevant details.	All variables are clearly described with most relevant details.	Most variables are clearly described with most relevant details.	Variables are not described OR the majority lack sufficient detail.
Scientific Concepts	Report illustrates an accurate and thorough understanding of scientific concepts underlying the lab.	Report illustrates an accurate understanding of most scientific concepts underlying the lab.	Report illustrates a limited understanding of scientific concepts underlying the lab.	Report illustrates inaccurate understanding of scientific concepts underlying the lab.
Analysis	The relationship between the variables is discussed and trends/patterns logically analyzed. Predictions are made about what might happen if part of the lab were changed or how the experimental design could be changed.	The relationship between the variables is discussed and trends/patterns logically analyzed.	The relationship between the variables is discussed but no patterns, trends or predictions are made based on the data.	The relationship between the variables is not discussed.

Summary	Summary describes the skills learned, the information learned and some future applications to real life situations.	Summary describes the information learned and a possible application to a real life situation.	Summary describes the information learned.	No summary is written.
Drawings/ Diagrams	Clear, accurate diagrams are included and make the experiment easier to understand. Diagrams are labeled neatly and accurately.	Diagrams are included and are labeled neatly and accurately.	Diagrams are included and are labeled.	Needed diagrams are missing OR are missing important labels.
Data	Professional looking and accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled.	Accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled.	Accurate representation of data in written form, but no graphs or tables are presented.	Data is not shown OR is inaccurate.

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BATTERY DESIGN LAB

Day 5: Proposal Day

TASKS	**COMPLETION**
Team work day to prepare written and oral proposal for the City Manager and City Council members addressing the needs that the battery designs should meet: battery should provide as much voltage as possible for the least amount of money. Remember that additional desirable criteria include portability, lightweight, and safe/green.	
Use rubric to guide your presentation.	

Notes:

Note: Day 6 is the presentation! Be prepared!

Presentation Rubric

CATEGORY	4	3	2	1
Group Work	The group functioned exceptionally well. All members listened to, shared with and supported the efforts of others. The group (all members) was almost always on task!	The group functioned pretty well. Most members listened to, shared with and supported the efforts of others. The group (all members) was almost always on task!	The group functioned fairly well but was dominated by one or two members. The group (all members) was almost always on task!	Some members of the group were often off task AND/OR were overtly disrespectful to others in the group AND/OR were typically disregarded by other group members.
Research	Group researched the subject and integrated 3 or more "tidbits" from their research into their newscast.	Group researched the subject and integrated 2 "tidbits" from their research into their newscast.	Group researched the subject and integrated 1 "tidbit" from their research into their newscast.	Either no research was done or it was not clear that the group used it in the newscast.
Accuracy of Facts	All supportive facts are reported accurately (3 of 3).	Almost all facts are reported accurately (2 of 3).	One fact is reported accurately.	No facts are reported accurately OR no facts were reported.
Presentation of Content	Presentation accurately portrays the function of the battery and all battery components are discussed. Cohesive presentation.	Presentation accurately portrays the function of the battery but not all battery components are discussed.	Presentation either accurately portrays the function or discusses the battery components, but does not discuss both.	Presentation of content is choppy and no clear connection is made between battery components and function.
Speaks clearly	Speaks clearly and distinctly all of the time and mispronounces no words.	Speaks clearly and distinctly all of the time but mispronounces 1 or more words.	Speaks clearly and distinctly most of the time and mispronounces no words.	Does NOT speak clearly and distinctly most of the time AND/OR mispronounces more than one word
Graphics	Graphics include some original material and are clearly related to the material being presented.	Graphics are clearly related to the material being presented, but none are original.	Graphics include some original material but are only somewhat related to the material being presented.	Graphics are not related to the material being presented.

Appendix A:

How to Use a Voltmeter

http://www.ehow.com/how_16767_voltmeter.html

Step 1

Leave the meter OFF. Plug the probes into the meter. Red goes to the positive (+) and black goes to the negative (-).

Step 2

Turn the selector dial or switch to the type of measurement you want. To measure the voltage of a direct current source - a battery, for example - use DCV.

Step 3

Choose the range setting. The dial may have options from 5 to 1000 on the DCV side. This means it will measure from 5 volts to 1000 volts.

Step 4

Turn the meter on.

Step 5

Hold the probes by the insulated handles and touch the red probe to the positive (+) side of a DC circuit. Touch the other side (negative) with the black probe.

Step 6

Read the digital display or analog dial.

Appendix B:

Cost Analysis Information Bank

Metals

Lead	$1.0067/pound
Zinc	$1.0199/pound
Copper	$3.8499/pound
Aluminum	$1.3386/pound
Carbon	$.50/pound
Nickel	$.03/gram
	Hint: 1 pound = 453.59 grams

Solutions

Bleach	$1.85 for 709 mL
Cola	$.50 for 355 mL
Vinegar	$1.00 for 946 mL
Tomato Juice	$1.00 for 340 mL
Rip It Energy	$1.50 for 473 mL
Gatorade	$1.00 for 591 mL
Pine Glo	$1.00 for 1.892 L
Orange Juice	$1.00 for 532 mL
The Works	$1.00 for 709 mL
LA Totally Awesome	$1.00 for 591 mL
Isopropyl Alcohol	$.85 for 946 mL