Curriculum Units by Fellows of the National Initiative
2011 Volume V: Chemistry of Everyday Things

The Problems and Potential of Portable Power

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by Jennifer Fleck

Introduction

Chemistry is ubiquitous. The world around us is both composed of and can be understood by the interactions of the elements. Ironically, despite this inescapable truism, a significant portion of the general population either ignores chemistry on a daily basis or is even a little phobic about it. I must confess that I have been members of both camps in my lifetime. However, it seems as if every year, I gain both a deeper understanding of and appreciation for chemistry. I did not expect this to be the case, yet as I delved more deeply into life science or was "forced" to teach a few sections of chemistry, the power and promise of chemistry captivated me.

Thus, when I heard about "The Chemistry of Everyday Things," I was enlivened with possibility. The application of such subject matter seemed endless. Should I design a unit for a chemistry class, a course I have trouble escaping? What about the chemistry that goes on in living organisms? In the end, I settled on the intersection of the living and non-living worlds by selecting to do a unit for the course that I teach most frequently, Environmental Science. It was inescapable, in fact. For years, my students have been frustrated by the limitations of renewable resources during our energy unit. Why can't we just save the energy from solar panels? Why can't we store the energy from a windy day? Indeed, why can't we? One answer lies in the chemistry of batteries. Before my students can understand that, though, they need an understanding of the battery in general. Hence, my unit was born.

Rationale

This unit was written for a freshman environmental science class at a neighborhood (non-selective enrollment) public school on the southwest side of Chicago. According to the 2010 Illinois School Report Card, demographics of the school include: 0.7% White, 48.7% Black, 50.6% Hispanic, and 0.1% Native American. 97.3% of the students are low-income, and the Limited-English proficiency rate, which is defined as students who are eligible for transitional bilingual programs, is 8.5%. 18.6 % of the students have an Individualized Education Plan, and the Mobility Rate is 28.4%. The attendance rate is 73%, with 38.5% reported as chronically truant. 18.6% of students will drop out.

Regardless of this, as a wise person once told me, "kids are kids." In today's society that means that social media, communication and portable music are perceived as vital to their existence. Our students just can't seem to resist the lure of mp3 players and cell phones, and I have decided to capitalize on that as a hook for the second of three units in our freshman, Environmental Science course.

The unit previously consisted of a brief introduction to mechanical, electrical, chemical, light, heat, and nuclear energy and the conversions between them. Following this, the coal power plant was studied extensively. This focus served both to introduce electricity production and to provide a channel for the exploration of the environmental consequences of our reliance upon fossil fuels. To conclude the unit, the students were asked to plan a new power plant for one of three cities: Burlington, VT; Laramie, WY; or Albuquerque, NM. One of the criteria for the plant is that it not rely upon fossil fuels. Students utilize information obtained via a geographic information system (GIS) to identify resources such as solar energy, wind, and water in each locale as well as to map population densities.

Invariably, students soon begin to question the limitations in terms of storage and transportation for options such as solar and wind power. Batteries have the potential to fill that need. However, because batteries are not a major part of most school curricula, this unit is designed to give students the background necessary to apply batteries to their unit project, as well as to attain greater understanding of science as a process and the interactions of science and society.

Background Information

What Is a Battery?

Simply put, a battery is a device used to store electrical charge as chemical energy. There are many different formulations available today, but they can be separated into two main divisions, non-rechargeable or primary cells and rechargeable or secondary cells. Non-rechargeable batteries will discharge energy through one discharge cycle, at which time all of the chemical components will have been transformed into new compounds in an irreversible process. Conversely, the chemical reactions in rechargeable batteries can be reversed when an external power source is applied. [1] Figure 1 below shows the primary components, as well as serving as a comparison between the two types.

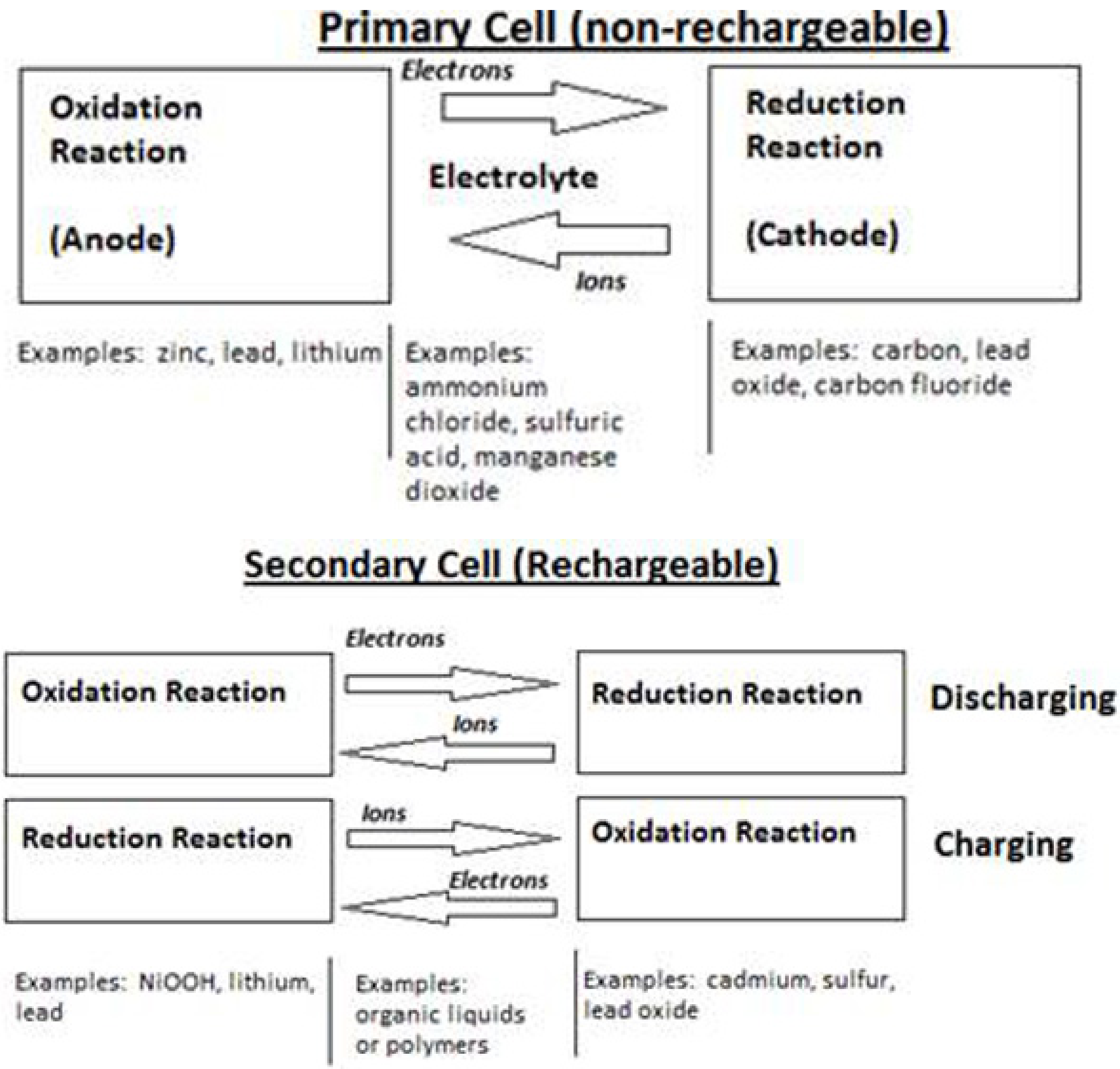

Figure 1

There are countless formulations for each type of battery, but a sample chemical reaction is shown below for a lead acid battery:

$$Pb + PbO_2 + 2H_2SO_4 \leftrightarrow 2PbSO_4 + 2H_2O^2$$

Note that the double headed arrow indicates that the reaction can proceed in both directions, indicating that this is a reaction that could occur in a rechargeable battery or secondary cell. Electrons would be freed when the reaction proceeds in the forwards direction, and adding electricity would cause the reaction to proceed in the reverse direction, thereby charging the battery.

Just as there are several formulations and chemical reactions used in today's batteries, there are also many different configurations. A generic diagram is shown below in Figure 2.

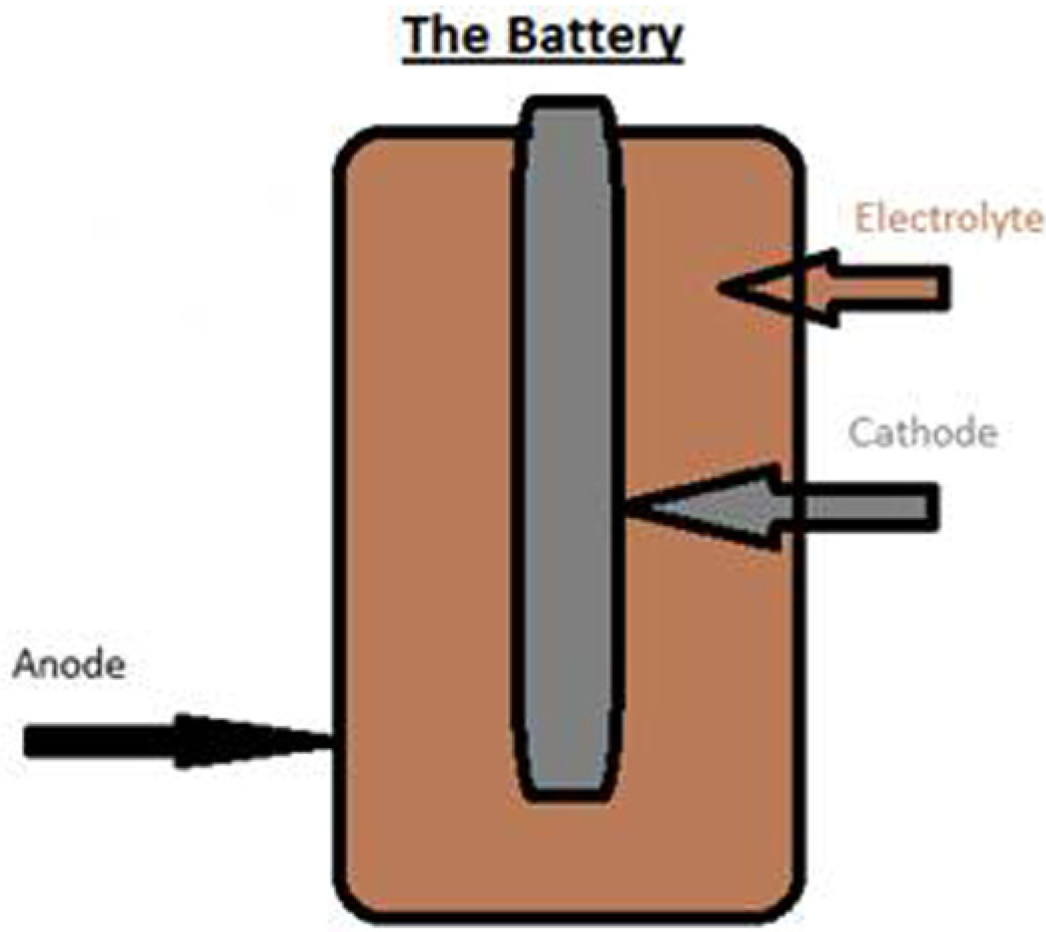

Figure 2: Shows a simple battery. The anode, where oxidation takes place, is shown in black, while the cathode, where reduction occurs, is shown in grey. The electrolyte is shown in brown.

A Brief History of the Battery

Given the extent to which electrical devices permeate everyday life, it is difficult to imagine a time "before" electricity. In fact, that is almost the case. While the dominance of electricity in society has occurred only over the past two centuries, electricity has been a source of wonder. As long ago as 1600 BC, amber, fossilized tree sap, was prized by the Greeks. They called it, "elektron" which came from the Greek word for gold due to its color. However, one of its most intriguing properties was that when rubbed, it would attract other objects. [2] Of course, we now know this phenomenon as static electricity. Since the amber was storing the electrical charge built up by rubbing it, Henry Schlesinger asserts that amber was, in fact, the first battery. [3]

It was not until 1600 AD, when British physician, William Gilbert, published his book *De Magnete*, that this attraction was understood to be caused by some movement of particles inside the amber, rather than due to a transfer of heat caused by the rubbing or from magnetic properties. [3] In 1906, J. J. Thomson received the Nobel Prize for discovering the negatively charged subatomic particle that came to officially be known as the electron in 1914. [3]

The first machine to hold a charge was the von Guericke generator, designed by Otto von Guericke in the mid 1600s. [3] This allowed both scientists and curious citizens to experiment with electrostatic charge. In 1706, Francis Hauksbee the Elder created a better device for storing electrostatic charge that enabled popular demonstrations. [3] One such gentleman, Charles-Fran?ois de Cisternay Du Fay, discovered that there were two charges, positive and negative. [3] By 1745, Ewald JÃ¼rgen von Kleist had used a device similar to von Guericke's generator to cause a glass filled with alcohol or mercury to glow. [3] This inspired others, such as Pieter van Musschenbroek and Andreas Cunaeus to create a device known as the Leyden Jar, "the first true electrical storage device." [3] This condenser/capacitor was replicated and used by other scientists as a source of electricity for their own experiments. [3] In an attempt to improve the jar, Daniel Gralath connected several jars in parallel and called it an "electrical battery." [3] However, it was Benjamin Franklin, shortly before performing his famous lightning experiment, who began to dissect the components of the Leyden Jar and improve upon them. [3] He, and others such as Thomas-Fran?ois D'Alibard, would later use the Leyden Jar as part of that famed experiment. [3]

By 1800, Alessandro Volta published a work that described how to construct a battery, and he also created the voltaic pile. [3] Because, the pile used chemical energy, rather than needing a charge like a Leyden Jar, and could sustain the electrical impulse for longer periods of time, this was a major advancement. [3] However, he did not provide much, if any, explanation of what created the charge. [3]

Shortly after this, Humphry Davy began to experiment with altering the materials used inside batteries, including the use of alkaline substances. Davy was also the first person to isolate lithium, which is the component of many batteries today. [3] Around this time, Antoine-Laurent Lavoisier had proposed that chemical and electrical affinity were the same. Davy demonstrated this through the synthesis and decomposition of water, concluding that electrical charges were holding the water molecules together. [3]

Other scientists were also experimenting with using different materials, and William Cruickshank incorporated copper and zinc plates surrounded by acid, into a wooden box, creating the first battery that was mass produced. [3] His battery and others, however, had the annoying characteristic of accumulating hydrogen bubbles on their copper plate, necessitating that the plate be removed and cleaned. [3] Then, in 1836, John F. Daniell, created a battery that contained a porous vessel that separated copper sulfate and dilute sulfuric acid, which prevented build-up and allowed for continuous use. [3]

Around this time, Faraday and a scientist named William Whewell began to use the term anode to describe the negative electrode, or the one that gives up the electron, and cathode to describe the positive electrode. [3] Meanwhile, Joseph Henry began experimenting with the use of multiple batteries and was the first person to create a parallel circuit, which resulted in greater amperage. By contrast, when he connected the batteries in series, the voltage increased. [3] Amperage and voltage have been described through the analogy of water in a hose, where volts are compared to the water pressure and amps are analogous to the volume of water in the pipe. [3] While working with electromagnetism, Henry also generated ideas that would later be used to design the telegraph. [3]

In the ensuing years, batteries powered objects from boats to telegraphs and the Transatlantic Cable to doorbells and stock tickers. [3] Yet everyone was still working with batteries containing dilute acid. Then in 1866, Georges Leclanché created the a battery that utilized ammonium chloride, or sal ammoniac as its electrolyte, manganese dioxide as its cathode and zinc as its anode. [3] This was a huge advantage, since it was less corrosive and could be replaced more easily by the average user. However, because it was suitable for only intermittent use, it worked best in applications such as doorbells. [3]

Another scientist, Gaston Planté, was active in battery research at this time as well. By 1889, he had developed the first rechargeable battery, the lead-acid battery. [3] Among other things, these were used for electric lighting. The well to do could rent sets of batteries and strings of electric lights, along with an electrician to maintain them, for a contracted amount of time during special events. [3] Alternately, a party host could also utilize the services of the Electric Girl Light Company, who would

> "furnish a beautiful girl of fifty or one hundred candle power, who will be on duty from dusk till midnight-or as much later as may be desired…This girl will remain seated in the hall until someone rings the front doorbell. She will then turn on her electric light, open the door, and admit the visitor and light him into the reception room. If, however, any householder should desire to keep the electric girl constantly burning and to employ another servant to answer the bell, there can be no doubt that the electric girl, posing in a picturesque attitude, will add much to the decoration of the house."[4]

From theatrical costumes to electric irons, fans, sewing machines, automobiles, the flashlight, the toaster, the electric handshake buzzer used in practical jokes today, electric pens, and the phonograph, the battery was making its way into everyday life. [3] At the 1893 World's Columbian Exposition in Chicago, it also powered moving sidewalks, the Electric Building, and small boats. [3] Furthermore, the battery enabled Elisha Gray and Alexander Graham Bell to invent the telephone, but it had its downside as well. Excited by the promise of this magical power, some began to apply it to medicine, leading to applications that ranged from quackery to dangerous. [3]

One major drawback of the battery during this time, however, was that it still required much maintenance. Felix Lalande and George Chaperson developed a battery, now referred to as the Lalande battery that placed copper and zinc electrodes into an alkaline solution housed in a ceramic container. [3] The only maintenance required was to periodically change the electrolyte, making the job of those who maintained the telegraph lines much simpler. Lalande also created a version which housed the components inside a sealed, porcelain container, making it suitable for use in the home. [3]

Meanwhile, Carl Gassner was inventing the first dry cell. [3] Dry cells were maintenance free and are the batteries still used today in most simple consumer electronics. It was both applied to existing technology, such as telegraphs, as well as allowed the creation of a wide array of novelty items. [3] Companies such as Ever Ready and Energizer and the precursors to Rayovac and Duracell were born. [3]

By the turn of the 20th century, batteries were powering the wireless telegraph, which was brought to the public by Guglielmo Marconi. Radio soon followed, with applications during the first World War and popularity both commercially and in the hands of hobbyists. [3] Perhaps the most major development, however, came between 1917 and 1919, when the National Bureau of Standards met with representatives from industry to develop a set of specifications for the standardization of batteries. [3] In doing so, they not only noted size and voltage, but also gave the batteries names. [3] This was of huge benefit to consumers. Although the power grid was advancing and electricity was becoming increasingly commonplace for applications such as lighting and radios in urban areas, rural areas still relied exclusively upon batteries. [3] Samuel Ruben even merged the grid and the battery through the invention of a device called the "trickle charger," which allowed batteries to remain charged by connecting them to a household outlet. [3]

World War II saw increased use of the battery for countless portable devices. It also led to the creation of a battery called the proximity fuse, which could be placed inside a shell and did not began to discharge until the shell was fired. [3] Other great advancements were made during this time by companies such as Motorola in terms of decreasing the size and weight of batteries used for communications. [3] However, batteries were still very sensitive to the environments in which they operated. For example, the heat and humidity of combat in tropical environments caused batteries to run down too quickly. [3] This was remedied by Samuel Ruben, who made the first new chemical advance in batteries in a century, when he created the mercury cell. [3] The P. R. Mallory Company, which later became Duracell, packaged them in steel and churned them out for the troops. [3] They would later be used in the exploration of space. [3]

Although other substitutions were also made, such as including cadmium in place of mercury, the limitations of batteries were eventually reached when appliances, such as radios, required more than a few vacuum tubes for operation. [3] Faraday had previously described the First Law of Electrolysis, which states that "in order to double the output of any battery, the amount of material in that battery must be doubled." [5] Nonetheless, new applications, such as the battery powered wristwatch, continued to appear. [3] Then in the middle of the 20th century, John Bardeen and Walter Brattain of Bell Labs invented the transistor, eliminating the need for vacuum tubes and enabling batteries to once again play a prominent role in electronics. [3] The common dry cell also made advancements during this time period, when Lewis Frederick Urry created an alkaline battery which utilized powdered zinc, thereby greatly increasing the surface area for chemical reaction to take place and giving it a much longer lifespan. [3]

Other advances in electronics, such as the development of the integrated circuit or IC, which decreased the size and increased the portability of electronics, also propelled the battery forward in terms of its utility for everyday life. [3] As consumer electronics continued to advance, so did the batteries used to power them. The end of the 20th century saw the creation of the "jelly roll" battery, in which the battery components were rolled together to increase the surface area of the components. [3] Rechargeable batteries also increased in use so that alkaline, nickel cadmium, NiMH, and lithium batteries all increased in prevalence. [3]

Yet Faraday's Law continues to plague us today. Alkaline batteries seem suited only for use in applications requiring relatively low voltage, while lithium-ion batteries have the most use, and NiMH batteries are somewhere in between. [3] Due to their toxicity and precise specifications needed to prolong battery life, nickel cadmium batteries are decreasing in terms of use. [3]

Meanwhile, lithium-ion batteries are at the forefront of today's battery use. Lithium was first discovered as lithium aluminum silicate or petalite in Sweden in 1800. [3] Ten years later it was classified by Johan Arfwedson and named lithos because he believed it to be alkaline. [3] In the 1970s, Exxon and Eveready, attracted by the "high energy density" that seemed to defy Faraday's Law, [3] began to study its application to batteries. Due to safety concerns, however, they abandoned their study. NASA found limited applications in the decade that followed, but in the 1990s Sony and the Asahi Chemical Company brought the lithium-ion battery to the consumer market in full force. [3] Other Asian companies soon followed, and today they are a mainstay of consumer electronics. [3]

For the most part, however, lithium-ion batteries do not represent a significant shift in how batteries operate. Furthermore, for the last 200 years, objects have been created to work with the batteries that exist, so there has been little incentive for major advancements in battery technology. [3] Such an impetus may be close, however, due to the need to develop storage capacity for renewable energy. Although there is some interest in the advancement of other batteries such as the lead-acid battery, [6] most of the advances in battery technology are designed to work with a battery that utilizes lithium as an electrode. These include batteries in which sugar or alcohol is utilized as an electrolyte and even one in which urine is the electrolyte. [7] Another bio battery incorporates the bacteriophage M13 to produce the peptides that form single-walled carbon nanotubes for the electrode. [8] For others, the emphasis is on design in terms of consumer wants, such as batteries that will flex or bend. [9]

Unfortunately, although some advancements have been made, lithium batteries still pose a safety concern, so this is also an area in which progress can be made. One solution incorporates polyethylene microcapsules at the anode. Because lithium-ion batteries are known to overheat, causing fires, the capsules are designed to melt at increased temperature, stopping the movement of ions and thereby putting out the fire. [10] The self-healing polymer could also fill cracks caused by mechanical stress and prolong battery life. [11]

Development is also needed in terms of finding renewable sources of battery components and maximizing stored energy. [11] Such advancements could make them more competitive for storing energy produced via solar, wind, nuclear and geothermal resources. [12] Of course, we must also remain cognizant of the methods by which batteries are disposed. Concern has been raised most recently regarding the potential for zinc pollution due to litter [13] and incineration. [14]

Despite current limits of supply and concern regarding disposal, batteries may hold the key to our future energy needs. In addition, there is research on ultracapacitors and fuel cells that is promising. [15] As we seek to decrease greenhouse gas emissions and combat climate change, technologies such as solar and wind power become increasingly desirable means of meeting the needs of a power hungry, technological society. Unfortunately, the electricity produced via these means is intermittent due to the fact that the sun does not shine at night and wind power is unpredictable. Batteries have the potential to capture excess energy produced during the daytime or high winds for later use. Furthermore, other alternative energies, such as nuclear and geothermal energy can also benefit. [13] Because nuclear reactors supply a constant energy source while consumer use reflects times of peak consumption followed by periods of lower demand, the development of batteries and similar devices to store energy could minimize waste and enable us to meet the need during times of high demand more efficiently. Meanwhile resources such as geothermal and tidal power are limited in terms of location, so a device such as a battery would enable power from these sources to be transported to areas where those resources were previously not an option. These ideas will form the basis for the culminating activity for my unit.

Strategies and Activities

As mentioned in the background and rationale, this unit is designed to fit within the larger unit of my freshman environmental science course on energy. I plan to introduce the concept of the battery at the start of the unit, while we are studying the types of energy and transformation between the forms. This will be done via an inquiry lab in which students will identify the purpose of a battery by building upon a lab that is currently done in which students visit stations at which they witness and identify various energy transformations. This will be followed by a lab in which students will create their own battery using a modified version of the lab found in chapter 4, activity 6 of the book utilized by our chemistry students. [16] (See Appendix C: Battery Lab) This will be followed by partnership with our Equipment and Technology Institute students in which the sophomores in that course, upon completing their unit on batteries, would come in and teach what they have learned to our freshman environmental science students.

Throughout the year, our school works on College Readiness Standards once a week. During the time we spend on this unit, we will also be utilizing charts and graphs from articles on batteries for our work on these standards. Select articles for this work are presented in Appendix E.

After completing the battery lab and having the presentation from the ETI students, we will return to our exploration of energy resources in general. We will study the basics of a power plant and the environmental consequences of our reliance upon coal. However, we will decrease the temporal emphasis given to coal and increase the amount of time spent studying alternative energies. As we do so, we will return to the idea of batteries as having the potential to address current limitations of some alternative energy. At this time, it is my hope that this connection will happen organically, but if necessary, I will formally reintroduce batteries as we wrap up our exploration of renewable resources. This would mimic the history of batteries. Simple batteries, such as the Leyden Jar, were developed long before we had use for them. [3] Similarly, my students will study batteries prior to their formal introduction to alternative energy. However, once the potential to utilize batteries in conjunction with renewable energy is identified as a class, we will return to and study them in depth.

Students will read excerpts from *The Battery* by Henry Schlesinger and will develop a battery timeline. This will include the statement that

> "According to some experts, significant improvement in traditional battery technology may be coming to an end. The last major breakthrough, lith-ion batteries during the 1990s, say some experts, brought the industry close to the end of the line of usable materials. We are, they say, at the point of incremental improvements." [17]

Using this assertion a catalyst, students will be broken into groups to analyze journal articles on recent advancements in the area of battery technology. Since the articles vary in terms of their readability, groups will be formed based on homogeneous grouping of reading level. I determined the readability by typing the first sentence of each article into an online calculator. [18] The articles are listed in Appendix D and ranked according to their Flesch-Kincaid Grade Level, with A being the simplest, and H representing the most difficult. In cases where the entire article is not to be used, that is noted in the table as well. Because the reading level of the article is greater than that of the students in most cases, I will begin the lesson by stressing to the students that they are not expected to understand everything in the articles, but rather to get an understanding of the main idea, challenge themselves, and become familiar with various kinds of science writing. I will also work with each group privately, pulling out key points. Regardless of the article or its difficulty, students will individually answer the same questions, which are also shown in appendix D. They will then meet with their group members to check their answers and devise a means of presenting the information to the rest of the class.

To wrap up the unit, students will use the project from years past, in which they design a power plant for either: Laramie, WY; Burlington, VT; or Albuquerque, NM. However, the project will carry a new requirement, in that students will need to somehow incorporate the use of batteries (employing either current technology or advancements predicted for the foreseeable future) into their plan and subsequent presentation. Students will be cautioned to employ a "cradle to grave" philosophy in their consideration of the batteries and their impact on the environment.

Although, this unit will officially conclude with the completion of Unit 2 in March, I plan to revisit it briefly in April or May, when we make our second visit to Lake Michigan as part of our Adopt-A-Beach program. Because it is relatively easy to test for the presence of zinc in a water sample through the use of test strips, and because zinc was noted as one of the types of pollution resulting from battery litter and incineration, I think it will be interesting to see if it is present in our local water source. Of course, because zinc pollution can be due to other sources such as automobile tires, if zinc is present in Lake Michigan, its presence will not necessarily indicate battery litter. [19] However, this ambiguity would present the opportunity for my students to gain first-hand knowledge of the process of science wherein finding the "answers" to the object of our research always leads us to new questions. This, then, could lead to new research on the part of my students to determine whether there is a connection between the presence of zinc and battery waste.

Appendix A

Additional Resources for Students

Matt, Stephen R. *Electricity and Basic Electronics.* Tinley Park: Goodhear-Willcox, 2009.

This is the textbook used by our Equipment & Technology Institute. It has a nice description of the battery. It is does not cover much chemistry, but it does cover the basics of batteries.

Additional Resources for Teachers

Castelvecchi, Davide. "Batteries,"Scientific American301:3 (2009): 73. (Accessed via EBSCO*host)*

This article gives a general explanation of batteries.

Dodds, D. D, Kennety Buckle, C. Levy, and Donald A. Redelmeir. "Ask the Experts," *Scientific American* 295:3 (2006): 126. (Accessed via EBSCO*host*)

This question and answer section discusses how batteries store and discharge energy.

King, Anthony. "Lithium-the new oil," *Chemistry & Industry* 21:8 (2010): 18, 20.

This article is too technical for students, but it gives a great overview of both the benefits of lithium batteries and some aspects of them that are ripe for improvements.

Schumm, Brooke. "Nonrechargeable Batteries," June 2002, accessed July 16, 2011, http://electrochem.cwru.edu/encycl/art-b02-batt-nonr.htm

This website from Case Western Reserve University gives a very thorough explanation of primary cell batteries. It also includes links to pages on related concepts. For example, there are hyperlinks to pages on both electrodes and electrolytes.

Appendix B

Standards and Objectives

This unit is designed to accomplish both process and content goals in science. I feel that the following process goals are important: Students will be able to design an experiment, students will be able to identify the independent and dependent variables, and students will be able to write a hypothesis, using an "If...then...because..." format. These link to the following standards in Illinois:

- PSAE 11.11.01 Understand and follow procedures relating to scientific investigations, including understanding the design and procedures used to test a hypothesis, organizing and analyzing data accurately and precisely, producing and interpreting data tables and graphs, performing appropriate calculations, applying basic statistical methods to the data, identifying appropriate conclusions, making predictions, and evaluating competing models.
- PSAE 11.11.04 Distinguish and define the following components of typical experiments: constants, variables, experimental group, control group (or control setup).

In terms of content, students should be able to describe science as a way of knowing, marked by experimentation, replication and revision that leads to new understandings about how the world works. This understanding can then be applied as technology to solve the world's problems. They should also be able to describe the chemical processes that occur inside of a battery, describe a battery as chemical storage of electrical energy and electricity as the flow of electrons, and describe the impact of batteries on the environment from production to disposal. These statements align with the following goals in Illinois:

- PSAE 12.11.34 Understand how agricultural run-off and pollution entering ground water and surface water can affect drinking water and local wildlife.
- PSAE 12.11.60 Understand that most acids, bases, and salts, when dissolved in water, conduct electric current and form ions in water solutions. Understand the observable properties of acids, bases, and salt solutions.
- PSAE 13.11.06 Analyze scientific breakthroughs in terms of societal and technological effects.
- PSAE 13.11.07 analyze examples of resource use, technology use or conservation program and make recommendations for improvements. [20]

Appendix C

Students will engage in a laboratory activity to build a battery. In Part A, students will examine a "potato clock." This is made by inserting pieces of zinc and copper into a potato and connecting them to wires that are attached to an LCD clock. A diagram is shown below in Figure 3.

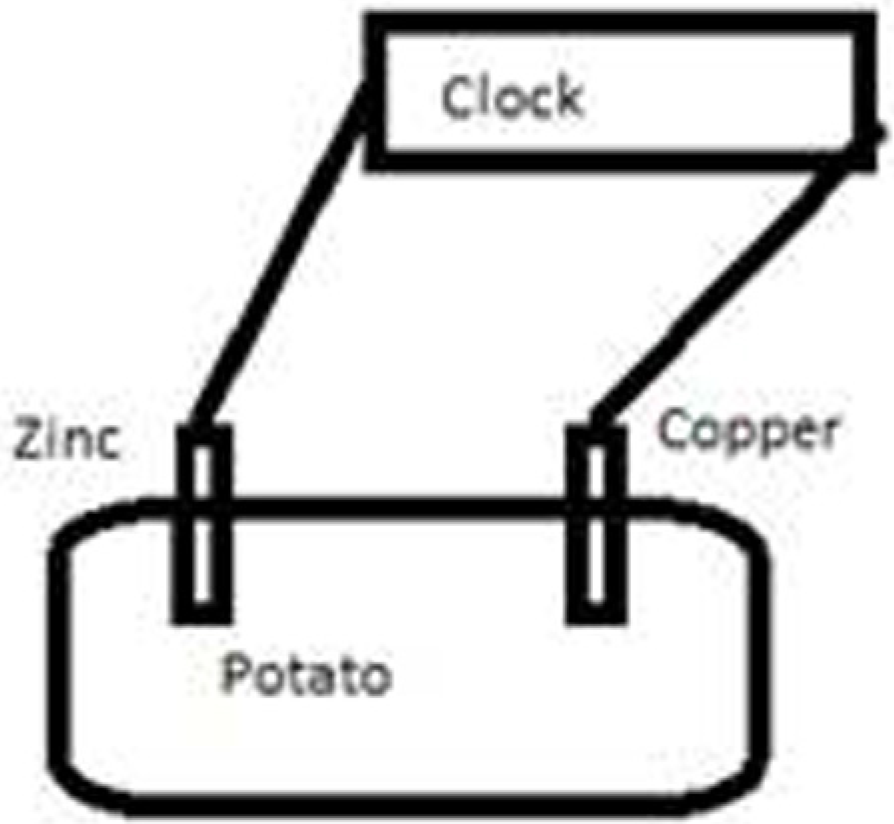

Figure 3

Students will answer questions about the set up and then be asked to create a battery using an item other than a potato. Student directions and questions aimed at understanding experimental design are included below.

In Part B, students will follow a procedure from our chemistry text [17] to create a battery using copper, zinc and sodium nitrate solutions. A picture is shown below in Figure 4 that demonstrates much of the setup, with the exception of a salt bridge, which can be made by filling a u tube with electrolyte and plugging the ends with glass wool or by soaking a paper towel in the electrolyte solution and placing each end into the beakers containing the electrodes below the solution level. The students will use this battery to light a light bulb.

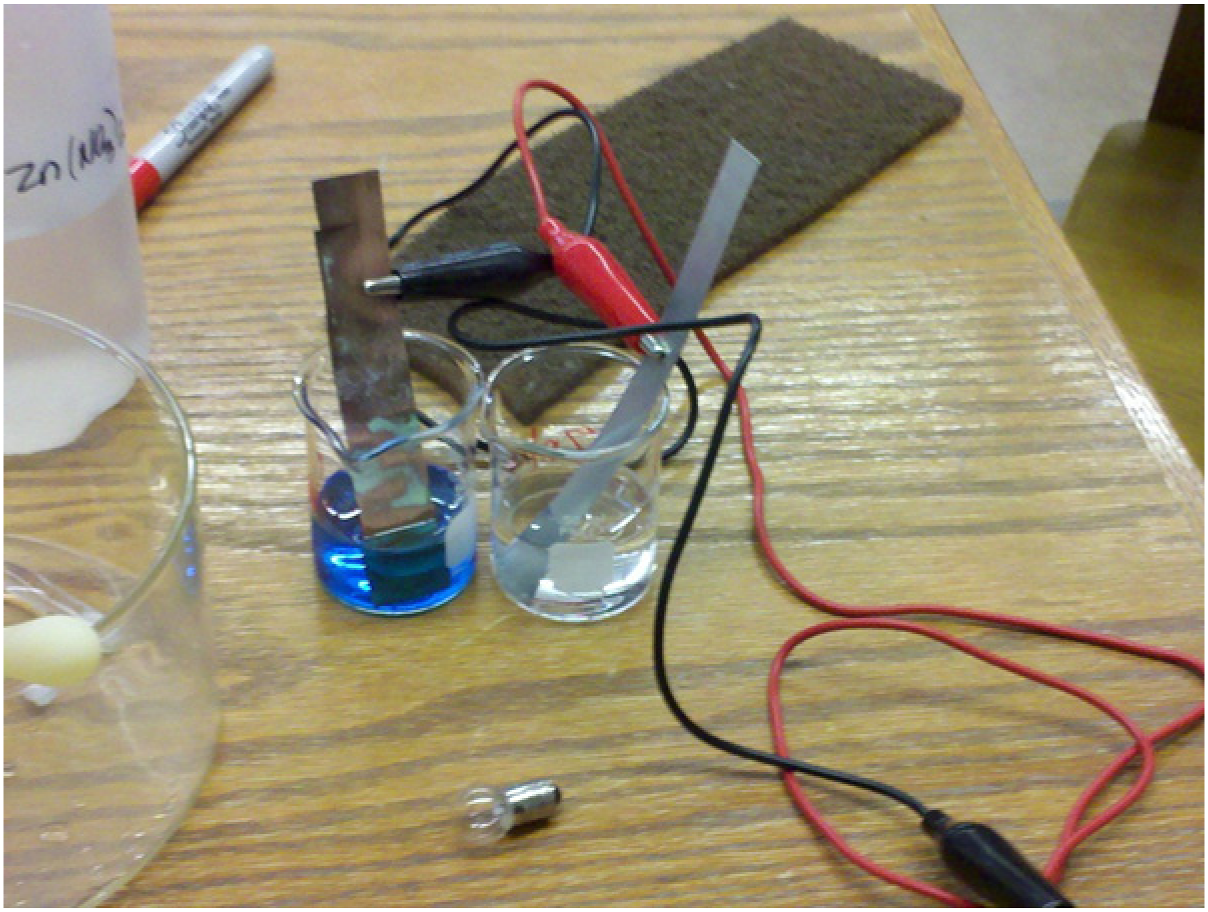

Figure 4

Battery Lab Part A

1) Examine the clock. How does it get its power? Make a sketch of what you see and label the role of each object (potatoes, wires, etc.)

2) What might be the effect of altering the set-up? What would happen if you used an orange, instead of a potato? What if you changed the size of the metal or wires?

3) Select one change that you would like to make. What we change is a **variable**. Is this an **independent variable** or a **dependent variable**?

4) Predict what will happen when you make this change. Your prediction is a **hypothesis**. Please state it in "If...then...because" format.

5) Draw a diagram of your new set-up. Show it to your teacher for approval.

6) Set up your new apparatus. What happens? Do the results support or disprove your hypothesis?

Battery Lab Part B

Follow the procedure for Part B: Making a Battery found on pages 309-311 of the *Active Chemistry* book. Your teacher will put the answer to step 4 on the board for you, and we will discuss it at the end of the lab.

**Extension (Extra Credit): What effect do you think varying the solutions contained in the two beakers would have?

Appendix D

Article	Article Name	Selection	Flesch-Kincaid Reading Level
A	"Not An Option"[21]	All	6.49
B	"electric highway"[22]	All	10.10
C	"Taking the heat out of lithium batteries"[23]	All	12.78
D	"Charging about town"[24]	All	13.87
E	"Building better batteries"[25]	Only pages 652 and 653 and Table 1 and Conclusions on page 656-657	14.64
F	"Racing Green"[26]	All	17.61
G	"Lithium-the new oil"[27]	All	18.20
H	"Urban Battery Litter"[28]	Abstract, Introduction, Table 2, Summary and Conclusions only	18.74

Questions

1) In one sentence, please state the main idea of your article.

2) What was the purpose of your article?

A) Summarize changes/advancements in the field of batteries or laws governing them

B) Present new research

C) Give an opinion about an area of science related to science/editorial

3) Why should we care about your article?

4) List the key points that you should present to the class.

Appendix E

Resources Including Charts and Graphs

Burke, Andrew. "Batteries and Ultracapacitors for Electric, Hybrid, and Fuel Cell Vehicles," *Proceedings of the IEEE* 95:4 (2007): 806-820.

Goodenough, John B. and Yougsik Kim. "Challenges for Rechargeable Li Batteries," *Chemistry of Materials Review* 22 (2010): 587-603.

Scrosati, Bruno and JÃ¼rgen Garche. "Lithium batteries: Status, prospects and future," *Journal of Power Sources* 195 (2010): 2419-2430. doi: 10.1016/j.jpowsour.2009.11.048

Endnotes

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