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STEM teaching in a chemistry laboratory "How to build a simple battery in the laboratory"

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Abstract

Active learning, especially STEM education, has been proven to help students develop their learning skills. Most teachers are encouraged to create activities and environments that help students to learn not only about theories involved in each lesson, but also help them to develop skills required in the 21st century. The STEM approach is used in a laboratory in a Chemistry for Engineers course at Mae Fah Luang University on the topic of electrochemistry. The battery is used as a real world application of electrochemistry. The lesson plan of a 2.5-hour laboratory session based on STEM is presented in this article. Starting with concept engagement on the subject of batteries, students use their inquiry skills to search for information about batteries. The following activities are hands-on experiences in using batteries to power light bulbs, construct galvanic cells and create a functioning battery to power a light bulb using galvanic cells. The final challenge was to create a battery from galvanic cells to produce the brightest light bulb. After class, students' self-evaluations showed that the activities helped them to understand the scientific concepts involved in electrochemistry, as well as concepts of current, voltage and electricity. They also thought that the activities helped to improve their critical thinking and team-working skills.

Keywords: STEM, Battery, Electrochemistry, Chemistry laboratory

1. Introduction

In the world of education, all progressive teachers have realized that old fashioned lecture-based teaching needs to be replaced with more active learning and teaching. Developments in technology have had a huge impact on education at all levels. Nowadays, the Internet is first point of inquiry for most students. The classroom has changed in order to engage students with various activities including reading, writing, discussion, or problem solving that promote analysis, synthesis, and evaluation of class content [1]. These activities are active learning methods. A variety of active learning techniques have been proposed and applied to curricula at various levels over the past decade [2-4]. Most methods have similar aims, i.e., to equip students with skills required in the 21st century so that they will be successful both in work and life. The world needs active citizens who not only have content knowledge but also show social and emotional competencies to navigate multifaceted life and work environments [5].

Among active learning and teaching methods, STEM education has its own characteristics. STEM teaches science, technology, engineering and mathematics using an interdisciplinary and applied approach [6-9]. It is most important to link STEM with the real world applications [10-11].

Figure 1 Materials and equipment

This paper presents a lesson plan for a 2.5-hour laboratory session in a Chemistry for Engineers course. The course was designed for first-year students in the Materials Engineering program at Mae Fah Luang University. The STEM approach used to teach the concept of electrochemistry is presented here.

2. Materials and methods

Each group of students was provided with materials and equipment (Figure 1). Their kits included alkaline batteries,

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Table 1 Sessions and timing for 2.5 hour laboratory

Sessions	Timing
Concept engagement on batteries and their uses	20 min
Activity 1: Powering a light bulb with alkaline batteries	20 min
Activity 2: Science of a battery (electrochemistry)	30 min
Activity 3: Powering a light bulb with a simple galvanic cell	30 min
Activity 4: Challenge to produce the brightest light	30 min
Discussion and conclusions	20 min

a small light bulb, a voltmeter, alligator clip wires, small metal strips (zinc, magnesium, copper) to be used as electrodes, electrolyte solutions ($Zn(NO_3)_2$, $Mg(NO_3)_2$, $CuSO_4$) and salt bridge material.

3. Lesson plan

The topic is set for a 2.5 hour laboratory session in a Chemistry for Engineers course at Mae Fah Luang University. The lesson plan was designed to use a STEM education approach and it is shown in Table 1.

S (science) is focus on the chemistry in a battery which relates to the electrochemistry, the concept of a Redox reaction and transfer of electrons. The concepts in physics such as voltage, current and electrical power are alsodiscussed. T (technology) used in the project is the use of a voltmeter, calculator, light bulb, and Internet inquiry. E (engineering) involves how to construct a function battery using simple galvanic cells. M (mathematics) is the calculation of electromotive force using Nernst's equation, the calculation for the number of galvanic cells needed for a functioning battery.

3.1 Concept engagement

Students are grouped together as 5-6 persons. Each group is asked to provide information on batteries. The students will use their inquiry skills to bring together details of how a battery is built, the development of batteries, and the differences in the various types of batteries, among other things. The instructor encourages them to discuss the importance of batteries in their daily life among their peers. After that, the instructor asks some or all groups to share with the rest of the class.

At the end of this session, students should know that there are a variety of battery types available in the market. They may get the idea that different batteries are powered by different chemical reactions.

3.2 Activity 1: Powering a light bulb with alkaline batteries

Commercial alkaline batteries (AA type) and small light bulb are given to each group. They need to power up the light bulb with the provided batteries.

The instructor will motivate each group to discuss among their peers, the requirements for powering the light bulb. The instructor may guide the students to look into the concepts of voltage and current. A simple circuit diagram of how to connect the battery to the light bulb may be presented by students as shown in Figure 2.

In this activity, the students will gain experience on how to connect the wires with battery and the light bulb. From this hands-on activity, they will identify the positive/negative terminal of the light bulb. They will learn that the light bulb requires certain number of AA batteries to power it. The

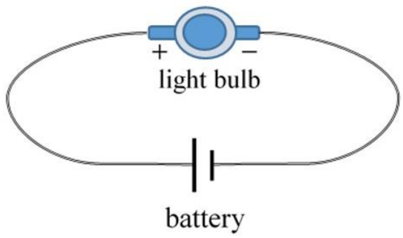

Figure 2 Simple circuit diagram

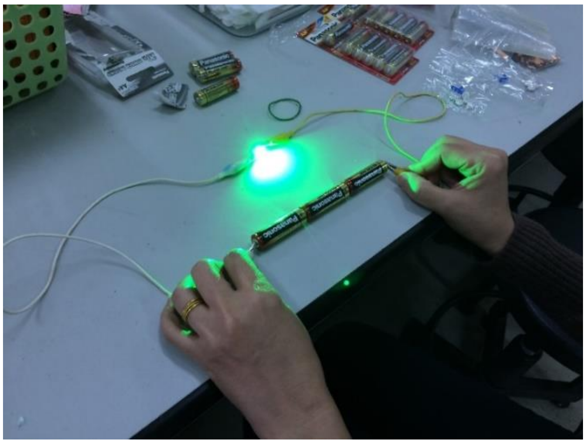

Figure 3 Powering a light bulb with AA batteries.

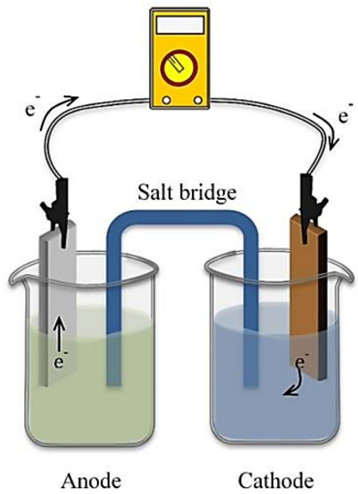

Figure 4 Schematic drawing of galvanic cell

instructor will ask each group "what is the minimum voltage needed to power the light bulb?" Each group is asked to show the class how they powered the light bulb as shown in Figure 3.

Table 2 Students' self-evaluation results

This project helps me to understand the concept of electrochemistry.	4.63
This project help me to understand the concept of current, voltage, electricity.	4.78
This project help me to improve the teamwork skill.	4.67
This project help me to improve the critical thinking skill.	4.78
I would like to learn from project based like this one.	4.67

3.3 Activity 2: Science of a battery (electrochemistry)

In this activity, the students will learn the concept of electrochemistry. A concepts of a Redox reaction, electromotive forces, a galvanic cell, cathode, and anode are discussed. Each group will construct two galvanic cells and use a voltmeter to measure the value of the electromotive force (E_{cell}), as shown in Figure 4.

The first galvanic cell is constructed using $Zn|Zn^{2+}$ as an anode and $Cu|Cu^{2+}$ as a cathode. A second galvanic cell uses $Mg|Mg^{2+}$ as an anode and $Cu|Cu^{2+}$ as a cathode. Each group is asked to record the values of E_{cell} of both galvanic cells. The instructor will initiate a discussion on why the obtained voltages are different. The students are instructed to compare the experimental values to those of the theoretical values.

The theoretical value of E_{cell} can be calculated from the Nernst's equation (Equation (1)) [12]. E^{o}_{cell} is the standard electromotive force, Q is the reaction quotient and n is the number of electrons involved in the reaction. E^{o}_{cell} is calculated using the standard reduction potentials (E^{o}) of the cathode and anode through Equation (2).

$$E_{cell} = E^{o}_{cell} - \frac{0.0592}{n}\log Q \quad (1)$$

$$E^{o}_{cell} = E^{o}_{cathode} - E^{o}_{anode} \quad (2)$$

3.4 Activity 3: Powering a light bulb with a simple galvanic cell

After activities 1 and 2, the students will combine the information and plan to construct a battery from a galvanic cell selected from activity 2 r to power a light bulb. Using the values of E_{cell} and the minimum requirement of voltage to light the light bulb, students will demonstrate their engineering skill in making a function battery from simple galvanic cells. Each group is asked to share their work and idea with the rest of the class.

The instructor may set a competition and give a reward to the first group that can power the light bulb with galvanic cells to promote an active classroom.

3.5 Activity 4: Challenge to produce the brightest light

Now that the students can power a light bulb using commercial AA batteries and simple galvanic cells, the instructor will ask them to compare the brightness of the light from both battery systems. The instructor will motivate students to discuss among their peers about why the brightness is different and what could be the cause. The concepts of electric power (P), current (I) and voltage (V) are needed to apply Equation (3).

$$P = IV \quad (3)$$

The brightness of a light bulb depends directly on the electric power input. The students may try to increase the electric power by increasing either the applied voltage or current flows in the circuit. The size of metal sheets, the concentration of electrolytes, and the number of cells may be the topics of discussion.

In the last activity, the students are given a challenge to build a battery from galvanic cells and power a light bulb to give the brightest light. They will show their creativity in how they can improve their battery to obtain a brighter light. All groups will show their work to the class and determine which group has the brightest light (Figure 5).

At the completion of the laboratory session, approximately 20 minutes for discussion and conclusions will help students to wrap up all the concepts in the science behind batteries.

Figure 5 Who has the brightest light?

4. Students' self-evaluation

Once all activities have been completed, the students are required to do their self-evaluation based on their satisfaction. They answer questions with a point system ranging from 1 to 5. A score of 1 means least satisfied and 5 means most satisfied. The students' self-evaluation results are shown in Table 2. The average scores were all above 4.5. Therefore it can be concluded that the students were happy with the STEM-based activities. In terms of science concepts, the activities helped students to understand topics in physics, i.e., current, voltage and electricity slightly better than for chemistry. This may have been since they have equipment to measure those values, so they could observe when the values changed. Oxidation and reduction reactions cannot be detected as clearly. Students believed that the activities helped them to improve their critical thinking skill as well as their ability to work as a team.

5. Summary

This paper provides a lesson plan for a chemistry laboratory on the topic of electrochemistry. The activities for the class are based on STEM. Electrochemistry is the science behind batteries, which is very important in our daily lives. The students had hands-on experience in construction of galvanic cells and use the cells as batteries to power a light bulb. During the 2.5 hours laboratory session, students practiced inquiry and inquiry skills, collaboration in teams and presentation skills. The overall outcome is that they can create a functioning battery using simple galvanic cells and formulate some ideas on how to improve them. The results from students' self-evaluation show that the activities helped them to understand concepts such as current, voltage and electricity and also improve their critical thinking skills.

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