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Problem-Solving Skills of Students in Electrochemistry Using a Flipped Classroom Model

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ABSTRACT

The pedagogical practice of the flipped classroom model (FCM) was undertaken to determine the students' problem-solving skills in electrochemistry. A quasi-experimental design was used in this study using two contrasted groups, experimental group (flipped classroom) and control group (conventional classroom). The freshmen civil engineering students were the respondents of the study. Five factors of problem-solving skills were used as a scheme interpretation of student's answers such as (a) Problem Comprehension; (b) Understanding Relationships Among Chemical Concepts; (c) Understanding Associated Chemical Concepts (d) Applying Appropriate Problem-Solving Strategies; and (e) Using Appropriate Mathematics. Results revealed that student's under the flipped class was of better problem comprehension and can relate chemical concepts to the problem than the conventional class. Most of the students can do mathematical calculations in both groups but failed to explain the underlying concepts. Many students have many misconception statements on the oxidizing-reducing agents and the flow of electrons in the anode to cathode. The spontaneity of the cell was also the least understood. Nonetheless, many students can solve the

standard and non-standard *E*cell potential and Gibbs free-energy (ΔG^o). Ergo, the flipped classroom teaching is a successful teaching approach in enhancing the problem-solving skills in learning electrochemistry.

Keywords — Education, problem-solving skills, electrochemistry, flipped classroom model, quasi-experimental design, Philippines

INTRODUCTION

Electrochemistry is a fundamental topic in chemistry. It involves many problems such as balancing redox reactions, electrochemical cells; standard electrode potentials (E°); Nernst equation; electrolysis; and corrosion. Consequently, solid mathematical operations are necessary to solve electrochemistry problems that students prove hard to do (Tsaparlis & Malamou, 2014). Indeed, electrochemistry topped as a challenging topic for many students, particularly in high school and even at the university level (Lin, Yang, Chiu, & Chou, 2002; Necor, 2019). The voltaic and electrolytic cells are challenging to understand because these topics are abstract, and the process is invisible to the eye, while only the effect is observable (Corriveau, 2011). An investigation of pre-service chemistry teachers conducted by Ekiz, Kutucu, Akkus, and Boz (2011), revealed that pre-service teachers could not distinguish electrolytic cells from galvanic cells. Moreover, pre-service teachers have difficulty identifying the anode and cathode in an electrolytic cell; hence, they could not identify the product of the electrolysis processes (Ekiz et al., 2011).

From these difficulties, teachers should find ways to improve the conceptual knowledge and algorithmic ability of the students. One possibility is using varied teaching strategies with an integration of technology (Necor, 2018). Many researchers reported success in utilizing computer animation to correct misconceptions. This is apparent in the particle movement in a voltaic and electrolytic cell (Ekiz et al., 2011).

One of the goals of science education is to develop the student's problem-solving skills. Problem-solving requires overcoming all the impediments in reaching a goal. Relatively, various scholars defined problem-solving in a variety of ways. Reid and Yang (2002) stated that inappropriate chemical knowledge prevents students' problem-solving ability in chemistry. It becomes unsuccessful if chemistry instruction does not provide an adequate set of rules to follow or does not help them to understand chemical knowledge during the learning process.

Hence, it is essential to help students to understand the pre-requisite knowledge and skills of problem-solving.

A problem is anything that gives rise to doubt and uncertainty. According to Wheatley (1984), problem-solving is defined broadly as not knowing what to do. It requires logical and creative thinking (Bybee & Sund, 1990). Moreover, Gagne (1977) defined problem-solving as a logical method by which the learner discovers a combination of learned rules that he can apply to solve a different problem. Pizzini and Shepardson (1992) put forward a similar argument by stating that it is a method of learning and an outcome of learning.

Problem-solving skills are specifically crucial in the quantitative problems of chemistry such as electrochemistry. Nakhleh, Lowrey, and Mitchell (1996) pointed out that students find it challenging to solve quantitative chemistry problems such as the mole concept. These difficulties might stem from the learner's psychological development, mathematical anxiety, visual abilities, and the employed instructional methods (Reid & Yang, 2002). Thus, it is necessary to enhance new learning environments by incorporating instructional strategies to uplift the learning of abstract science. Successful problem solvers exhibited more effective problem-solving skills such as organization, persistence, evaluation, heuristics, and formal operations than unsuccessful problem solvers. Despite these skills, it has been noted that representation is essential for solving some difficult problems (Greenbowe, 1983). When students work on a problem, the first step is to find and understand the problem. If they do not follow a problem at the beginning, they cannot solve the problem successfully. Many activities such as imaging, inferencing, decision-making, and retrieving knowledge from memory have been used to help students understand the problem.

Greenbowe (1983) investigated the variables involved in chemistry problem-solving. In his study, thirty college chemistry students and one college chemistry professor solved chemical stoichiometry problems. He found that successful problem solvers could construct and use an appropriate representation for the issues, and their conceptual understanding influenced the problem representation. Theoretical knowledge and representation are reciprocal causation. In light of difficulty, it seems to be practical to use an appropriate representation to solve some difficult problems. Therefore, if teachers want pupils to answer these difficult problems, they might find it helpful to emphasize representation skills.

In today's situation, face-to-face teaching-learning is impossible to meet due to the pandemic that the entire world is facing. Hence, teachers are using blended teaching-learning to engage students. The majority of the teachers around the world opted to use technology to effectively teach the students. Flipped classroom instruction is a teaching approach in which the typical lecture and homework elements of a course are reversed. Video lectures are commonly seen as a key ingredient in the flipped classroom model (Educause, 2012). Students view short video lectures at home or outside classes before the class discussion at their pacing. At the same time, the in-class time is devoted to exercises, assessments, or discussions. Flipped classroom instruction facilitates the transformation of the pre-existing incorrect knowledge into a scientific one. From this aspect, the flipped classroom can be viewed as a conceptual change and constructivist teaching approach. It effectively provides a learning environment in which students use their knowledge actively, construct their views about science, and develop critical thinking (Necor, 2019). It also creates a learning environment that allows students to change their incorrect conceptions to scientific conceptions (Bunce, 2015). The term "flipped classroom" was coined by two high school chemistry teachers from Colorado, Bergmann and Sams (2012, who began flipping courses in 2007. The flipped classroom model has spread to many other teachers, professors, and professional development educators worldwide.

The flipped classroom creates opportunities to increase student engagement, more faculty-student contact, and deeper learning (Jarvis, Halvorson, Sadeque, & Johnston 2014). The flipped classroom can also reduce cognitive load during classes (Sirhan, 2007; Seery & McDonnell, 2013). According to Fulton (2012), the advantages of the flipped classroom include: (1) students move at their own pace, (2) doing "homework" in class gives teachers better insight into student difficulties and learning styles, (3) teachers can more easily customize and update the curriculum and provide it to students 24/7, (4) classroom time can be used more effectively and creatively, (5) teachers using the method report seeing increased levels of student achievement, interest, and engagement, (6) learning theory supports the new approaches, and (7) the use of technology is flexible and appropriate for modern education (Herreid & Schiller, 2013). In recent years, the Flipped classroom has gained a high reputation in both K-12 and higher education, particularly in a pandemic. The flipped classroom tends educators to rethink the learning environment and consider how precious class time is maximized. Ruddick (2012) used a flipped classroom for a college chemistry preparatory course. His students watched videos at home and spent class time working on problem-solving activities. Students under flipped classrooms have higher grades than regular lecture sections (Herreid & Schiller, 2013; Necor, 2019). Necor (2019) further suggested that the flipped classroom has high performance than conventional classes in electrochemistry after the intervention. He found out that the students in the flipped classroom has higher final exam scores and overall success in class. In addition, the flipped classroom brought positive impacts toward students' learning activities such as achievement, motivation, engagement, and interaction (Zainuddin & Halili, 2016). Zainuddin and Halili (2016) also added that flipped classroom abides by the theory of Bloom's revised taxonomy for the cognitive domain. They suggested that students may learn lower levels of cognitive work (gaining knowledge and comprehension) at home or outside of class and focus on the higher forms of cognitive work (application, analysis, synthesis, or evaluation) in a class by hands-on activities or practice. The flipped classroom is more interesting and feels less intimated in chemistry class, and online videos and PowerPoint materials are useful (Herreid & Schiller, 2013). Teaching flipped classrooms supports chemistry laboratory experiments conducted by Teo, Tan, Yan, Teo, and Yeo (2014) provided teachers with great flexibility over the classroom time as students have time to engage lesson content at a deeper level.

FRAMEWORK

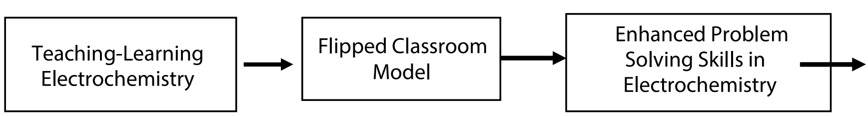


Figure 1. The Conceptual Framework of the Study

Algorithmic (or problem-solving) skills are an essential ability in quantitative problems, particularly in electrochemistry. Electrochemistry ranked as one of the most challenging topics in chemistry for both high school and college-level students. It is also apparent to the chemistry teachers. Electrochemistry involves redox reactions, standard electrode potentials, E^0; *Nernst* equation, electrochemical cells, electrolysis, and industrial applications.

Consequently, strong mathematical skills are necessary to solve electrochemistry problems that students proved hard to do (Tsaparlis & Malamou, 2014). The concepts in electrochemistry are said to be abstract, and many students have misconceptions and problem-solving difficulties (Corriveau, 2011). Corriveau (2011) suggested that voltaic and electrolytic cells are difficult to understand. Tsaparlis and Malamou (2014) also noted that the electron flow through a salt bridge and electrolyte solutions, the anion and cations in the salt bridge, and the electrolyte solution transfer electrons from the cathode to the anode and half-cell potential are also least understood. The investigation of pre-service chemistry teachers conducted by Ekiz et al. (2011) revealed that teachers could not even distinguish electrolytic cells from galvanic cells.

Similarly, they could not recognize the electrodes as anode and cathode in electrolytic cells, so they could not correctly predict the product of the electrolysis (Karaçöp, 2016). Hence, teachers must look into different teaching strategies to address misconceptions and problem-solving difficulties. And one of those is the use of flipped classroom model instruction.

The flipped classroom model is a pedagogical approach in which direct instruction moves from group learning to individual learning. The resulting group learning space transformed into a dynamic, interactive learning environment in which a course's typical lecture and homework elements were reversed. The Flipped classroom has gained a high reputation in recent years and has enhanced conceptual understanding and algorithmic skills in teaching chemistry classes. The students under flipped classroom performed better in all tests and quizzes, outperformed the standard lecture-based students, more interested and less intimated, supports chemistry laboratory experiments with great flexibility, and a significant increase in sequential exams. Hence, this model will enhance problem-solving skills and develops scientific reasoning in learning electrochemistry.

Enhanced problem-solving skills are one of the goals of science education, known as a higher-order cognitive skill to achieve a scientifically literate society. The problem-solving skills can be evaluated by specific characteristics such as problem comprehension, understanding relationships among chemical concepts, understanding associated chemical concepts, applying appropriate problem-solving strategies, and using relevant mathematics.

OBJECTIVES OF THE STUDY

This study assessed the effectiveness of flipped classroom instruction on the problem-solving skills of freshmen civil engineering students in learning electrochemistry. Furthermore, this study was conducted to determine the effect of flipped classroom instruction on students' problem-solving skills in electrochemistry.

METHODOLOGY

Research Design

This study used a quasi-experimental design to compare students' problem-solving skills. Two contrasted specified instructional models-conventional (control) and flipped classroom model (experimental) were utilized. The respondents were freshmen, civil engineering students. Both groups were handled by the researcher throughout the course. The selection of respondents was made via a purposive sampling technique based on the criteria appropriate for the study. The respondents were matched based on respondent's scores in Lawson's Classroom Test of Scientific Reasoning (Lawson, 2000). This matching ensured that the respondents from both groups (experimental and control) are equivalent or of comparable capabilities. A flipped classroom instruction was used for experimental groups, while the control group was exposed to conventional instruction. In the flipped classroom, each student is required to have online access outside classes to each video posted. All the students in the flipped classroom were enrolled in the google classroom created by the researcher. The videos were downloaded from reputable sources such as Youtube.com. All the videos were pre-watched before posting.

Instrumentation

In this study, an Electrochemistry Problem-Solving Ability Test (EPSAT) developed by the researcher was used. The score of a student in the test was interpreted as his/her problem-solving ability in electrochemistry. This test served as a basis for student's problem-solving skills and conceptual understanding in electrochemistry after interventions to both groups. The test was content-validated by chemistry instructors who have been teaching chemistry for more than five years. A test/retest was used to determine the reliability of the test.

Table 1. EPSAT Sample Problems 1 & 2

1. The equation below is an oxidation-reduction reaction in an acidic solution.

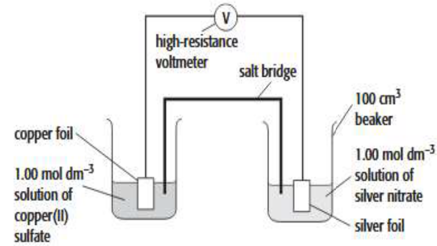
$$Cu_{(s)} + NO_3^-{}_{(aq)} \rightarrow Cu^{2+}{}_{(aq)} + NO_2{}_{(g)}$$

   a) Which element are being oxidized and reduced?
   b) What are the oxidizing and reducing agents? Explain.
   c) Write the reduction and oxidation the half-reactions.
   d) Write the balanced redox reaction in acidic solution using the half-reaction method.

2. The diagram below shows an electrochemical cell involving two metal/metal-ion systems. The standard electrode potentials for the half-cells are also shown below.

$$Ag^+ + e^- \rightleftharpoons Ag \qquad E^\ominus = +0.80\,V$$

$$Cu^{2+} + 2e^- \rightleftharpoons Cu \qquad E^\ominus = +0.34\,V$$



In this cell reaction;

a) Which substance is oxidized and reduced?
b) In which direction do the electrons flow? Explain your answer.
c) What are the cell voltage and the overall cell reaction?
d) What is the equilibrium constant (*Kc*) of the cell?

The test is suitable for two hours. Scores were based on a rubrics scoring scheme based on how and what students included in their solutions and the problem-solving skills required/or demonstrated with each score. The percentage correct responses of students were obtained and transcribed carefully. The EPSAT consisted of seven problems containing sub-questions. Each sub-questions were used to assess such as (a) problem comprehension, (b) understanding relationships among chemical concepts, (c) understanding associated chemical concepts, (d) applying specific problem-solving strategies, and (e) using required mathematics. Table 1 shows a sample EPSAT problem.

The Problem-Solving Ability Rubric (PSAR) adapted different rubrics as cited by Gayon (2007). In scoring the EPSAT, a PSAR was used, as cited by Gayon (2007). This scoring rubric probed the concepts, strategies, and mathematics used by the students in their problem-solving process. It also evaluated problem comprehension and understanding of relationships among chemical concepts. A corresponding score for the level of performance was given for each solution, manifesting specific characteristics of the five (5) factors of problem-solving: (a) problem comprehension, (b) understanding relationships among chemical concepts, (c) understanding associated chemical concepts, (d) applying appropriate problem-solving strategies, and (e) using relevant mathematics. The maximum number of points per factor was three (3) points. Each problem has a total of 15-points. A scoring scheme and verbal interpretation were used to interpret students' performance in each factor and the EPSAT, as shown in Table 2. To further evaluate the factors underlying chemistry problem-solving ability, the mean score for each factor was computed, and scoring was developed, as shown in Table 2. The researcher and another chemistry teacher independently checked each answer to ensure reliable and valid analysis.

Table 2. Scoring Scheme for Interpreting Student's Performance in Each Factor

Percentage Score	Verbal Interpretation
81-100	Outstanding
61-80	Very Satisfactory
41-80	Satisfactory
21-40	Fair
0-20	Poor

Factors Underlying Electrochemistry Problem-Solving Ability Test (EPSAT)

According to Gayon (2007), factor analyses were used to determine the factors underlying the chemistry problem-solving ability. It aimed to establish that the five factors targeted by sub-questions in the EPSAT are the factors of chemistry problem-solving ability. In this study, five factors were used, such as (a) Problem Comprehension, (b) Understanding Relationships Among Chemical Concepts, (c) Understanding Associated Chemical Concepts, (d) Applying Appropriate Problem-Solving Strategies, and (e) Using Appropriate Mathematics. The effectiveness of FCM in learning electrochemistry was determined by weighted scores in EPSAT. An independent two-sample *t*-test at a 5% level of significance was used to compare their scores for each factor.

Factor a: Problem Comprehension

It refers to the ability of the students to understand the problem by extracting and interpreting meaning from an expression or message. It involves translating chemical names to symbols, identifying variables to be solved or relevant variables needed to solve the problem, and considering constraints.

Factor b: Understanding Relationships among Chemical Concepts

It refers to the ability of students to understand and apply the associated concepts (Molarity, Voltage, Electricity, and Activity Series) to the problem. It involves the selection and implementation of relevant chemical concepts without any misconceptions.

Factor c: Underlying Associated Chemical Concepts

It refers to the ability to relate concepts involved in the problem. The concepts or quantities may be directly or indirectly stated in the problem. It is measured in terms of the number and correctness of relevant relationships among the chemical concepts. For example, correct explanation about reducing/ oxidizing agents, the flow of electrons in the cell, and spontaneity of the cell.

Factor d: Applying Appropriate Problem-Solving Strategies

It involves selecting and implementing a strategy that shows how the solution progresses from goal to general concepts and to arrive at a correct answer. For instance, can choose an appropriate strategy (e.g., calculation of *emf*; determine the net reactions; draw and label the Galvanic cell) needed to solve the problem.

Factor e: Using Appropriate Mathematics

It accounts for student's mathematical skills as applied to the specific problem. It probes the solution to the problem following numerical (e.g., algebraic and arithmetic) rules. It also involves a demonstration of understanding through the consistent use of mathematical language. In this study, the students can understand and apply relationships among numbers. In the sub-questions on Electrochemistry, the students are required to determine the *emf*; Gibbs free-energy (ΔG); the anode and cathode; and electrode potential. It inferred that students would not solve the problem correctly, even if they know the concept behind it.

Table 3. Problem-Solving Ability Rubric (PSAR) for problem 1 (factor a, b, c, d, and e)

Level of Performance (Score)	Factor (a) Problem Comprehension	Factor (b) Understanding Relationships among Chemical Concepts	Factor (c) Understanding Associated Chemical Concepts
3	▪ Identifies what is to be computed for in the problem ▪ Supports answer with the correct solution	▪ The solution includes at least 4 relevant relationships among chemical concepts (e.g., reduced/oxidized; reducing/oxidizing agent) ▪ Gives correct relationship between species being oxidized/ reduced) ▪ Gives correct explanation	▪ Selects and implements the relevant chemical concepts without any conceptual errors (e.g., half-reactions; reduced/ oxidized; reducing/ oxidizing agents, etc.)
2	▪ Identifies what is to be solved but fails to give an accurate answer. ▪ Does not support the answer with solution	▪ The solution includes 3 relevant relationships among chemical concepts ▪ Gives the correct relationship between reducing/oxidizing agents but fails to explain correctly.	▪ Evidence that the student has misconceptions ▪ Fails to consider a relevant concept needed to solve the problem correctly
1	▪ Fails to give an accurate answer and/or solution to either question. ▪ Gives a partially correct answer.	▪ The solution includes 1 or 2 relevant relationships among chemical concepts ▪ Fails to give the correct relationship between molarity and amount of solute	▪ Evidence that the student has several misconceptions ▪ Fails to consider several concepts needed to solve the problem correctly
0	▪ Nothing written ▪ Complete misunderstanding of the problem ▪ Only repeats information in the problem.	▪ Nothing written ▪ Fails to give correct relationship among chemical concepts	▪ Nothing written ▪ Only repeats information in the problem ▪ Gives a wrong answer and fails to show the solution

Level of Performance (score)	Factor (d) Applying Appropriate Problem-Solving Strategies	Factor (e) Using Appropriate Mathematics
3	▪ Selects and implements appropriate strategy (e.g., breaking the problem into steps, identifying sub-goals) needed to solve the problem. ▪ Solution progresses from goal (e.g., Balancing Redox half-reaction) to general concepts (e. oxidized/reduced, oxidizing/reducing agent) to answer (e.g., balanced redox reaction)	▪ Demonstrates understanding through consistent use of mathematical language (e.g., oxidation number, balancing of charges) ▪ Demonstrates correct balancing of redox reaction including a balanced number of elements and charges.
2	▪ Fails to carry out the strategy far enough (e. g. computation only up to oxidizing/reducing agents) ▪ The plan could give led to a correct solution if implemented properly	▪ Sparse use of language (e.g., numbers sense, charges, elements)
1	▪ The solution does not proceed past the basic statement of concepts (e.g., oxidizing/reducing agents) ▪ Partially correct plan based on the part of the problem being interpreted correctly	▪ Solution terminates for no apparent reason. ▪ When an obstacle is met, "math magic" or other unjustified relationship occurs. ▪ When an obstacle is met, the solution stops.
0	▪ Nothing written ▪ Difficult to assess ▪ Inappropriate strategy	▪ Nothing written ▪ Inappropriate strategy

Table 4. Problem-Solving Ability Rubric (PSAR) for problem 2 (factor a, b, c, d, and e)

Level of Performance (Score)	Factor (a) Problem Comprehension	Factor (b) Understanding Relationships Among Chemical Concepts	Factor (c) Understanding Associated Chemical Concepts
3	▪ Identifies what is to be computed for in the problem ▪ Supports answer with correct computation (e.g., cell voltage and *Kc* of the cell)	▪ The solution includes at least 4 relevant relationships among chemical concepts (e.g., reduced/oxidized, electron flow, electrode) ▪ Gives the correct relationship between reduced and oxidized and electro flow ▪ Gives correct explanation in electron flow in a cell	▪ Selects and implements the relevant chemical concepts without any conceptual errors (e.g., electron flow in a cell, metal preference)
2	▪ Identifies what is to be solved but fails to give an accurate answer. ▪ Does not support the answer with computation	▪ The solution includes 3 relevant relationships among chemical concepts ▪ Gives the correct relationship between reduced/oxidized electron flows in a cell but fails to explain correctly.	▪ Evidence that the student has misconceptions ▪ Fails to consider a relevant concept needed to solve the problem correctly
1	▪ Fails to give an accurate answer and/or solution to either question. ▪ Gives a partially correct answer.	▪ The solution includes 1 or 2 relevant relationships among chemical concepts ▪ Fails to give correct relationship reduced/ oxidized in electron flow in a cell.	▪ Evidence that the student has several misconceptions ▪ Fails to consider several concepts needed to solve the problem correctly
0	▪ Nothing written ▪ Complete misunderstanding of the problem ▪ Only repeats information in the problem	▪ Nothing written ▪ Fails to give correct relationship	▪ Nothing written ▪ Only repeats information in the problem ▪ Gives a wrong answer and fails to show the solution

Level of Performance (score)	Factor (d) Applying Appropriate Problem-Solving Strategies	Factor (e) Using Appropriate Mathematics
3	▪ Selects and implements appropriate strategy (e.g., breaking the problem into steps, identifying sub-goals) needed to solve the problem ▪ Solution progresses from goal (e.g., standard electrode potential) to general concepts (e.g., electron flow, *Kc*, and cell voltage)	▪ Mathematics is correct; numbers are either substituted at each step or at the last step ▪ Demonstrates understanding through consistent use of mathematical language (e.g., number sense, number relationships, operations, algebra, or arithmetic)
2	▪ Fails to carry out the strategy far enough (e.g., computation only up to cell voltage and *Kc* of the cell) ▪ The Plan could be led to a correct solution if implemented properly	▪ Sparse use of language (e.g., numbers sense, number relationships, operations, algebra, or arithmetic) ▪ Solution violates mathematics (e.g., algebra, arithmetic)
1	▪ The solution does not proceed past the basic statement of concepts (e.g., cell voltage and *Kc* of the cell) ▪ Partially correct plan based on the part of the problem being interpreted correctly	▪ Solution terminates for no apparent reason. ▪ When an obstacle is met, "math magic" or other unjustified relationship occurs. ▪ When an obstacle is met, the solution stops. ▪ Serious math errors in cell voltage and *Kc* of cell voltage
0	▪ Nothing written ▪ Difficult to assess ▪ Inappropriate strategy	▪ Nothing written ▪ Used no mathematical language inaccurately

Data Gathering

The study started with the selection of first-year civil engineering classes taught by the researcher. One of the two classes was randomly assigned as the experimental group and the other as the control group through coin tossing. The LCTSR was administered for matching (Lawson, 2000). It was pointed out that not all students in the same class were part of the analysis. However, all the instruments were applied to all students in both classes. They were not aware of who is included or not included in the study. The fourteen participants out of twenty-five students were chosen as the closest, if not, exact matches. _A readiness test was administered in both groups to determine whether a review of these pre-requisite concepts was needed to teach before teaching the core topics in electrochemistry. The intervention ran for only 17 hours of the first semester. After this, both groups took the EPSAT.

Intervention Strategies

A flipped classroom instruction was an intervention used in the experimental group only. On the other hand, conventional instruction was used for the control group. In the flipped classroom model, students were required to watch videos and presentations before in-class discussions and activities using their laptops, desktop, or smart mobile phones. The students can browse, watch, or listen to the videos several times. They are also expected to do assignments to encourage them to watch the videos before coming to class. A total of 25 video lectures were posted over the course. The videos were downloaded from reputable sources and pre-screened by the researcher before posting. The students were notified of what to watch either in the class or in the google classroom. Guided notes were also available to help students take notes and focus on critical elements in the video lecture. The topics were also mirrored those of the lectures that were delivered in the control class.

RESULTS AND DISCUSSION

Students' Performance in Each Factor

To evaluate the factors underlying problem-solving ability, the mean score for each factor was computed using a scoring scheme. Table 5 shows the EPSAT factor, the mean score between experimental and control groups, and the percentage score for each factor. The experimental group has a weighted mean score of 29.43 (or 84.08%) of the 49 points maximum score indicating an outstanding interpretation (Table 5). In comparison, the control group has a very satisfactory interpretation (Table 5) with a weighted mean score of 26.31 (or 75.18%) of the 49 points maximum score. The experimental group has outstanding problem comprehension. They also have an outstanding ability to understand the relationship between chemical concepts and to apply appropriate mathematical calculations in most problems. Conversely, the control group has a general scheme of very satisfactory. Only two factors (factors d and e) obtained an outstanding general scheme in the control group.

Table 5. EPSAT Factor, number of items, maximum possible score, mean score, and percentage score for each factor

EPSAT Factor	Number of Items	Maximum Possible Score	Mean Score		Percentage Correct	
			Experimental	Control	Experimental	Control
a. Problem Comprehension	7	49	30.29	26.71	86.53	76.33
b. Understanding Relationships among Chemical Concepts	7	49	28.29	24.29	80.82	69.39
c. Understanding Associated Chemical Concepts	7	49	22.71	23.43	64.90	66.94
d. Applying Appropriate Problem-Solving Strategies	7	49	32.00	28.14	91.43	80.41
e. Using Appropriate Mathematics	7	49	33.86	29.00	96.73	82.86
Total	35	245	29.43	26.31	84.08	75.18

Legend: O = Outstanding
VS = Very Satisfactory

Table 6. Independent Sample *t*-test Comparing Each Factor of Seven Problems between Experimental and Control Group

Factor	Group	N	Mean	SD	SE	*t*	p= Value	
a. Problem Comprehension	Experimental	14	2.163	.7557	0.076	2.33	.0103<p=.05	S
	Control	14	1.908	.7744	0.078			
b. Understanding Relationships among Chemical Concepts	Experimental	14	2.02	.7319	0.074	2.61	0.0049<p=.05	S
	Control	14	1.735	.7937	0.080			

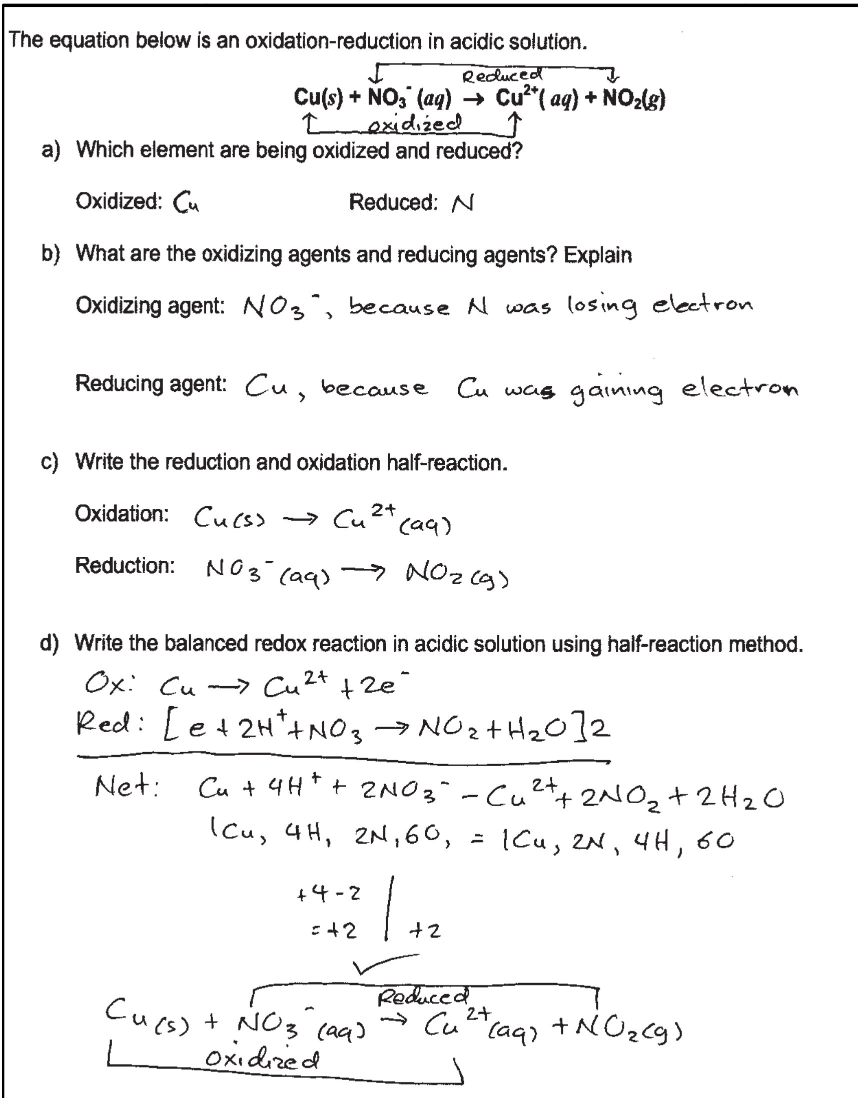
c. Understanding Associated Chemical Concepts	Experimental	14	1.622	.7932	0.080	1.15	0.126>p=.05	NS
	Control	14	1.490	.8151	0.082			
d. Applying Appropriate Problem-Solving Strategies	Experimental	14	2.286	.8249	0.083	2.25	0.0128<p=.05	S
	Control	14	2.01	.8909	0.090			
e. Using Appropriate Mathematics	Experimental	14	2.418	.8113	0.082	2.82	0.0027<p=.05	S
	Control	14	2.071	.9111	0.092			

Legend: S=significant, NS= Not significant

A comparison of mean scores for each factor in all items between two groups using a t-test for independent samples was calculated. It revealed that the mean scores were incomparable for factors a, b, d, and e but not in factor c, as shown in Table 6. The results suggested that the experimental group (flipped classroom) was of better problem comprehension. They can also relate chemical concepts to the problem. They can also perform and apply appropriate algorithmic calculations to the question as compared to the control group (conventional class). However, there was no significant difference in how the student explained the underlying concepts, or they held misconceptions statements even after the intervention, as shown in Figures 3 and 4.

In the study, it was found out that many students have difficulty relating the concepts involved in the problem. For example, students have difficulty explaining why certain species are oxidize and reduce agents in a redox reaction. Also, many of the students could not explain why the flow of electrons moved from anode to cathode. The spontaneity of the cell was also least understood by the students. Figures 3 and *4* show a sample answer by students in experimental #12 and experimental #21, respectively.

In *Figure 3,* the student failed to explain the reducing and oxidizing agent correctly. Though NO_3- was identified as an oxidizing agent, students could not clarify that N was being reduced (a decrease of oxidation number from $+5 \rightarrow +4$), so NO_3^- gains electrons. On the other hand, Cu was oxidized (an increase of oxidation number from $0 \rightarrow +2$); thus, Cu loses electrons.



The equation below is an oxidation-reduction in acidic solution.

Reduced

$$Cu(s) + NO_3^-(aq) \rightarrow Cu^{2+}(aq) + NO_2(g)$$

oxidized

a) Which element are being oxidized and reduced?

Oxidized: Cu Reduced: N

b) What are the oxidizing agents and reducing agents? Explain

Oxidizing agent: NO_3^-, because N was losing electron

Reducing agent: Cu, because Cu was gaining electron

c) Write the reduction and oxidation half-reaction.

Oxidation: $Cu(s) \rightarrow Cu^{2+}(aq)$

Reduction: $NO_3^-(aq) \rightarrow NO_2(g)$

d) Write the balanced redox reaction in acidic solution using half-reaction method.

Ox: $Cu \rightarrow Cu^{2+} + 2e^-$

Red: $[e + 2H^+ + NO_3 \rightarrow NO_2 + H_2O]2$

Net: $Cu + 4H^+ + 2NO_3^- - Cu^{2+} + 2NO_2 + 2H_2O$

1Cu, 4H, 2N, 6O, = 1Cu, 2N, 4H, 6O

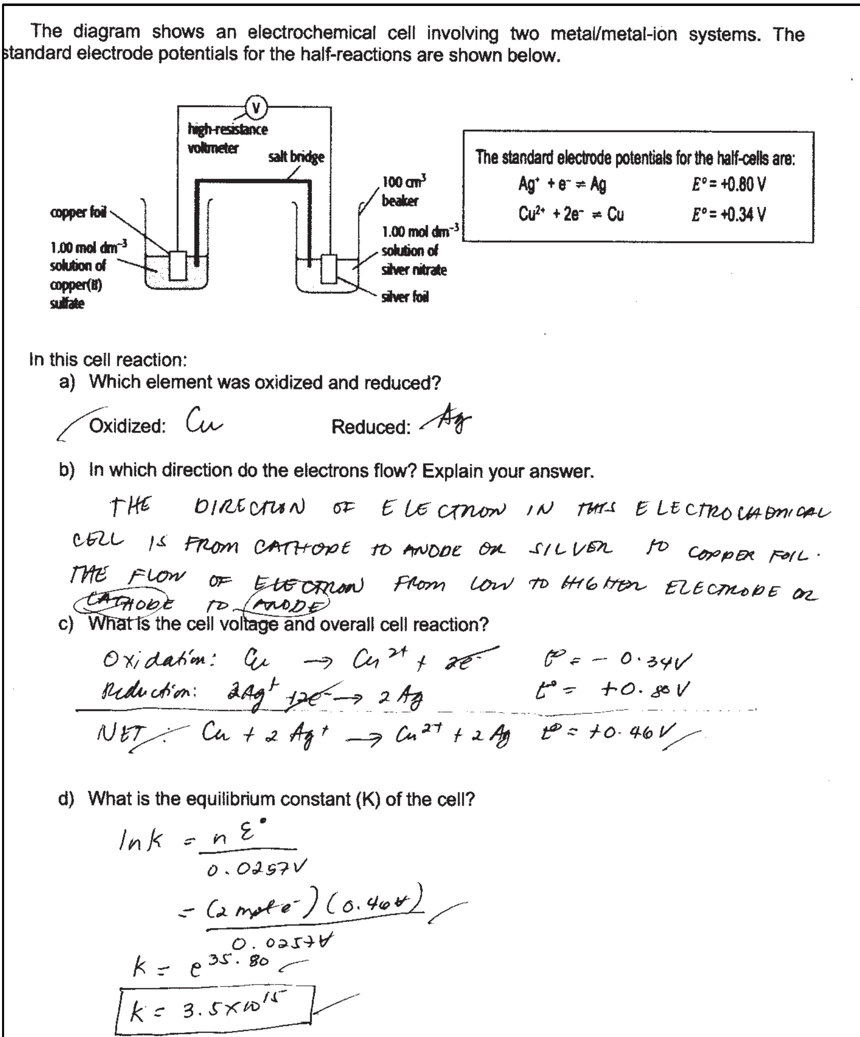
+4 - 2 = +2 | +2

Reduced

$$Cu(s) + NO_3^-(aq) \rightarrow Cu^{2+}(aq) + NO_2(g)$$

Oxidized

Figure 3. A sample answer by student E#12


The diagram shows an electrochemical cell involving two metal/metal-ion systems. The standard electrode potentials for the half-reactions are shown below.

In this cell reaction:

a) Which element was oxidized and reduced?

Oxidized: Cu Reduced: Ag

b) In which direction do the electrons flow? Explain your answer.

THE DIRECTION OF ELECTRON IN THIS ELECTROCHEMICAL CELL IS FROM CATHODE TO ANODE OR SILVER TO COPPER FOIL. THE FLOW OF ELECTRON FROM LOW TO HIGHER ELECTRODE OR CATHODE TO ANODE

c) What is the cell voltage and overall cell reaction?

Oxidation: $Cu \rightarrow Cu^{2+} + 2e^-$ $E° = -0.34V$

Reduction: $2Ag^+ + 2e^- \rightarrow 2Ag$ $E° = +0.80V$

NET: $Cu + 2Ag^+ \rightarrow Cu^{2+} + 2Ag$ $E° = +0.46V$

d) What is the equilibrium constant (K) of the cell?

$\ln k = \frac{nE°}{0.0257V}$

$= \frac{(2 mol e^-)(0.46V)}{0.0257V}$

$k = e^{35.80}$

$k = 3.5 \times 10^{15}$

Figure 4. A sample answer of E#21 on electrochemical cell

Figure 4 shows that the students can solve the E^0 potential and *Kc* of the cell. Nevertheless, he failed to explain correctly how the flow of electrons moved in the cell. In a galvanic cell (or Voltaic cell), electrons moved from the anode to the cathode. In the anode, there is a strong pull of electrons as compared to the cathode. Moreover, in the cell diagram, Cu was oxidized; thus, it loses electrons while Ag was reduced, thus gains electrons. For a cell to run, one species must lose, and the other species must gain an electron (Brown, LeMay, & Bursten, 2006). These concepts were not explained correctly by student E#21, as shown in Figure 4.

The following figures are the statements of students about the use of flipped classroom model (FCM) in learning electrochemistry. Students found flipped classroom helped him understand the concepts in electrochemistry independently, as shown in Figure 5.

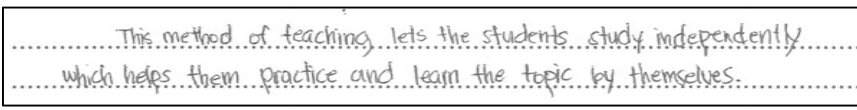

This method of teaching lets the students study independently which helps them practice and learn the topic by themselves.

Figure 5. Student E#8. Sample Comments in Flipped Classroom Instruction

They also perceived that flipped classroom is an effective way for them to learn. He also added that FCM is an easy and accurate way of learning. He also cited that other subjects must use FCM, as shown in Figure 6.

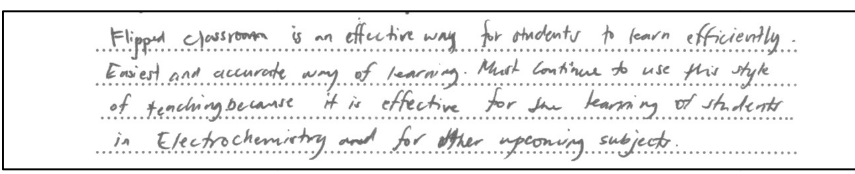

Flipped classroom is an effective way for students to learn efficiently. Easiest and accurate way of learning. Must Continue to use this style of teaching because it is effective for the learning of students in Electrochemistry and for other upcoming subjects.

Figure 6. Student E#5. Student comments in Flipped classroom model.

Additionally, student E#28 cited that FCM is an effective strategy because it helps them improve their critical thinking and independent learning, as shown in Figure 7.

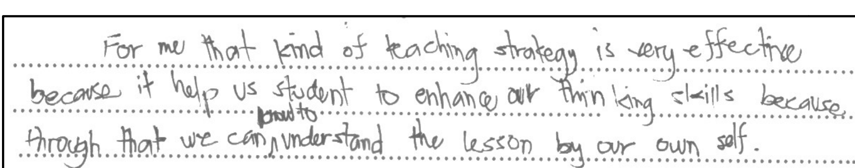
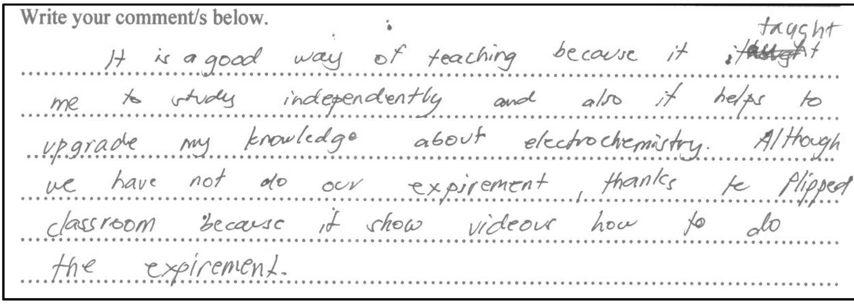

For me that kind of teaching strategy is very effective because it help us student to enhance our thinking skills because through that we can learn to understand the lesson by our own self.

Figure 7. Student E#28. Sample Comments in Flipped Classroom Model


Write your comment/s below.

It is a good way of teaching because it ~~taught~~ taught me to study independently and also it helps to upgrade my knowledge about electrochemistry. Although we have not do our expirement, thanks to flipped classroom because it show videos how to do the expirement.

Figure 8. Student E#23. Sample comments in flipped classroom

Student #23 quoted that FCM helped him understand electrochemistry in spite of lacking experiments because of some posted videos. Thus, FCM can suffice those experiments that cannot be done inside the laboratory, as shown in Figure 8.

CONCLUSIONS

Results showed that the flipped classroom model performed better compared to the conventional classroom in problem-solving skills. Furthermore, the experimental group (flipped classroom) has better problem comprehension. They also have a better understanding of relating chemical concepts to the problem. They can also perform and apply appropriate algorithmic calculations to the question as compared to the control group (conventional class). However, there was no significant difference in how the students explain the underlying concepts (or misconceptions statements).

The majority of the students in both groups were able to solve algorithmic problems. They calculate the E^ocell potential. They can also resolve issues about the equilibrium constant (Kc) in the cell. They can derive and solve problems involving standard and non-standard free energy (ΔG^o) in a cell. Though the majority of the students can calculate problems in electrochemistry, it was found out that many students held many conceptual misconceptions. This is prevalent in oxidizing and reducing agents in a redox reaction and the flow of electrons in a cell.

Moreover, some students cannot distinguish the spontaneity of the reaction. Some students have difficulty writing the correct line notation in a cell, the net cell equation, and E^o cell potential. They also have confusion on the salt bridge, as well as labeling the Galvanic cell diagram. Among the five factors of problem-solving skills, factors d (applying appropriate problem-solving strategies and e (using the suitable mathematical solution) were the highest in both groups. However, factor c (understanding associated chemical concepts) garnered the lowest correct answers in both groups. The flipped classroom model is one method teachers might consider as a vehicle to expose students to relevant technological learning resources.

TRANSLATIONAL RESEARCH

This study could reflect the teachers on their teaching experiences and encourage them to take a more active role in their professional development. Nowadays, the growth and adaption of the integration of technology paved away the landscape of effective science teaching. Hence, this study could provide insights into different ways of integrating new content-based pedagogy to encourage students to use critical thinking skills to solve curricular-based differentiated level problems. The flipped classroom model provides the platform from which students can take charge of their learning. It also gives both the students and the teachers the ability to develop higher-level critical thinking skills in a problem-posing student-centered learning environment. It can also be the potential to be an effective and beneficial method of science education, particularly in STEM courses and at the university level, which manifested benefits in teaching-learning in science and math courses. Consequently, the flipped classroom will help curriculum developers and course program writers plan electrochemistry under STEM or from a University level perspective.

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