Attainment of Learning Goals Associated with an Electrochemistry Experiment in a Large, Introductory Chemistry Laboratory Course

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Introduction

Testing student achievement of Learning Goals (LGs) in a reliable manner is essential to measure student learning and assess the effectiveness of curriculum reforms. Instruments, in the form of pre- and post- quizzes, were developed to assess student achievement of LG's in Experiment #11: Electrochemistry: Galvanic Cells and the Nernst Equation. Quizzes were validated with students and the Research Team, and underwent an extensive refining process before being employed pre- and post-experiment.

Experiment #11 is performed in the laboratory component of Chemistry 123, the second semester of the first year introductory chemistry course at the University of British Columbia. The course is required by all students in the faculty of science, as well as some in other faculties, and is comprised of > 1600 students, of which approximately 40% are male and 60% are female, and 35-45% identify as EFL (English First Language).

Experiment #11: Electrochemistry: Galvanic Cells and the Nernst Equation

Learning Goals[1]

Primary Concepts:
- Lab Safety
- Reference Electrodes
- Galvanic Cells
- The Nernst Equation

Experimental Procedure[1]:

Part I

Set up Galvanic cells; create and use an electrochemical series to predict voltages of other cells; test predictions.

Part II

Make calibration curve of E_{cell} vs. $\log[Cu^{2+}]$; Use with the Nernst Equation to calculate the concentration of an unknown.

Data Collection

- Pre- /post- lab quizzes administered 2 weeks prior and 2 weeks after the experiment
- Quiz split into 2 versions to reduce length
  - questions addressing the same LG kept together
- 50% students received the same version of post-quiz and 50% the alternate version to examine "pre-testing effect"
- Quiz scores and learning gains calculated
- In-lab observations assessed technique and safety LG's

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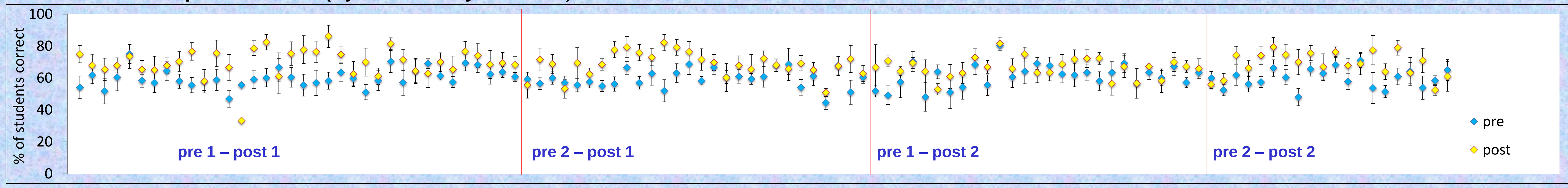
References

1. Nussbaum, S. et al. *Chemistry 121/123 Laboratory Manual: An Introduction to Chemical Research*. Department of Chemistry. University of British Columbia. 2009.
2. Marx, J.D., Cummings, K.J. Phys. Ed., 2007, 75, 87-91.

Results

Pre- and Post-quiz scores (by laboratory section)

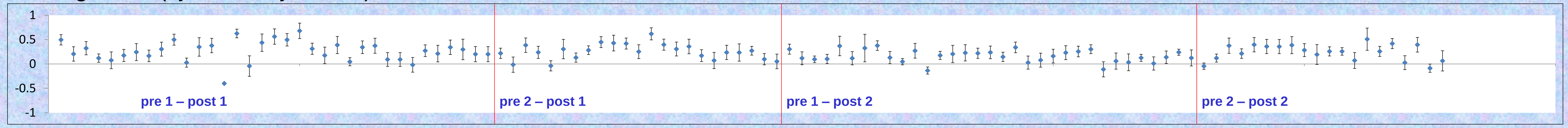


pre	post	pre avg (%)	post avg (%)
1	1	59.2 ± 1.1	69.7 ± 1.9
1	2	60.6 ± 1.6	66.6 ± 1.2
2	1	61.0 ± 0.9	69.9 ± 1.3
2	2	60.5 ± 1.1	67.8 ± 1.4

- Both tests are of the same difficulty
- No apparent pre-testing effect (Students who received the same and alternate versions of pre- and post- quiz did not score any differently on the post-quiz
- No apparent difference between sections

Average score improved from 60.3% (pre) to 68.5% (post)

Learning Gains (by laboratory section)



- Learning Gains were calculated based on the proposal for Normalized Change developed by Marx and Cummings[2].
- Measures student learning (or "negative learning") by assigning values from -1 to 1
- Since no pre-testing effect observed, and all sections deemed equal, can average learning gains for all sections

Average Learning Gain: 0.237

Pre- and Post-Scores by LG Concept

Consider the following half reactions:

$Ag^+(aq) + e^- \rightarrow Ag(s)$ (0.80V)

$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ (0.34V)

If all ions are at 1M concentration,

4. Will Ag(s) react with $Cu^{2+}(aq)$?

a) Yes, Ag(s) will be reduced.

b) Yes, Ag(s) will be oxidized.

c) No, they will not react.

5. Will $Cu_{(s)}$ react with $Ag^+(aq)$?

a) Yes, Cu(s) will be reduced.

b) Yes, Cu (s) will be oxidized.

c) No, they will not react.

Given the following half reactions:

$Nb^{3+}(aq) + 3e^- \rightarrow Nb(s)$ (-1.099V)

$Ti^{2+}(aq) + 2e^- \rightarrow Ti(s)$ (-1.630V)

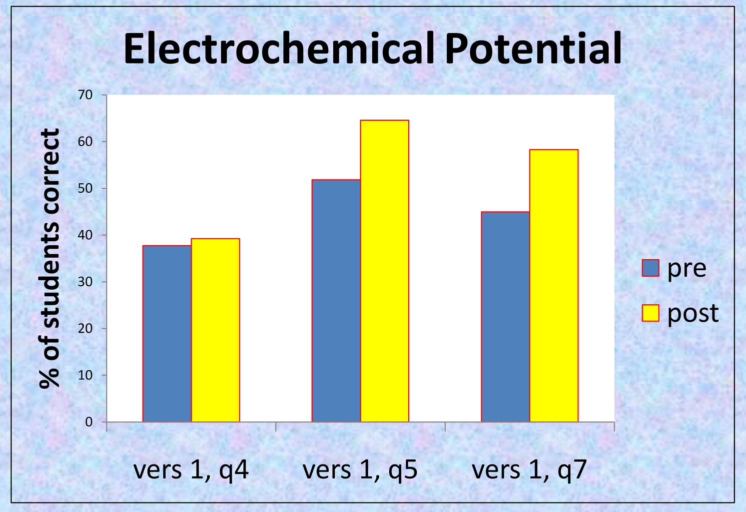
7. What is the balanced redox equation for Niobium (Nb) and Titanium (Ti)?

a) $3Ti^{2+}(aq) + 2Nb(s) + 2e^- \rightarrow 3Ti(s) + 2Nb^{3+}(aq) + 3e^-$

b) $3Ti^{2+}(aq) + 2Nb(s) \rightarrow 3Ti(s) + 2Nb^{3+}(aq)$

c) $3Ti(s) + 2Nb^{3+}(aq) + 3e^- \rightarrow 3Ti^{2+}(aq) + 2Nb(s) + 2e^-$

d) $3Ti(s) + 2Nb^{3+}(aq) \rightarrow 3Ti^{2+}(aq) + 2Nb(s)$



Students' understanding of oxidation and reduction concepts (q5) and balancing equations (q7) has improved, but understanding of electrochemical potential has remained low (q4)

Given the following reaction: $Mg(s) + Sn^{2+}(aq) \rightarrow Sn(s) + Mg^{2+}(aq)$

8. What is the galvanic cell notation for this reaction?

a) $Mg(s) | Mg^{2+}(aq) || Sn^{2+}(aq) | Sn(s)$

b) $Sn(s) | Sn^{2+}(aq) || Mg^{2+}(aq) | Mg(s)$

c) $Mg(s) | Sn^{2+}(aq) || Mg^{2+}(aq) | Sn(s)$

d) $Sn(s) | Mg^{2+}(aq) || Sn^{2+}(aq) | Mg(s)$

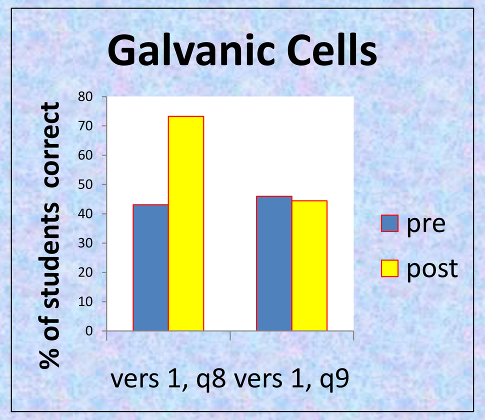
9. In the galvanic cell below, a strip of copper metal is immersed in a $CuSO_4$ solution and a strip of zinc is in $ZnCl_2$ solution. The half cells are connected by a $KNO_3(aq)$ salt bridge and the metals are connected to two poles of the voltmeter. The overall cell reaction is:

a) $Zn^{2+}(aq) + Cu(s) \rightarrow Zn(s) + Cu^{2+}(aq)$

b) $Zn^{2+}(aq) + 2Cu(s) \rightarrow Zn(s) + 2Cu^+(aq)$

c) $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

d) $Zn(s) + 2Cu^+(aq) \rightarrow Zn^{2+}(aq) + 2Cu(s)$



Students' ability to use galvanic cell notation has improved (q8), however their understanding of the redox reactions that occur in Galvanic Cells, and how Galvanic Cells work, did not change (q9).

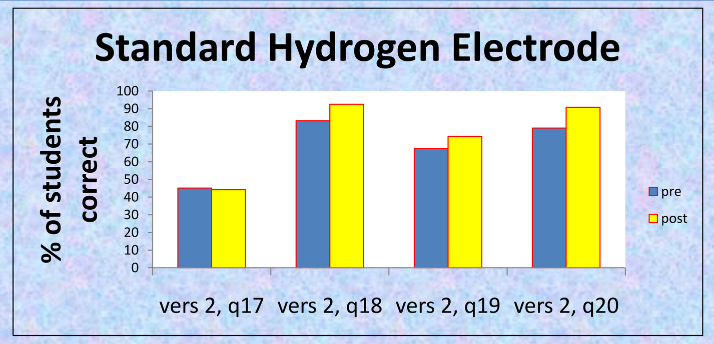
Which of the following statement(s) about the Standard Hydrogen Electrode (SHE) is/are true?

17. T F — It has a reduction potential of 0.0V.

18. T F — It is used as a reference point.

19. T F — Its reduction potential is set to 0.0V.

20. T F — The reduction potentials of other ions are measured relative to its reduction potential.



Use of a reference electrode is understood (q18,20) but "reference point" understanding is unclear (q17,19).

The Nernst Equation

Consider the galvanic cell:

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

Given the Nernst Equation:

$E_{cell} = E^{\circ}_{cell} - (2.303RT/nF) \log Q$

3. If water is added to dilute the $Cu^{2+}(aq)$ in the cell, how will the voltage be affected?

a) Voltage stays the same

b) Voltage will increase

c) Voltage will decrease

Why?

*4. **T** F — equilibrium shift to the right (products)*

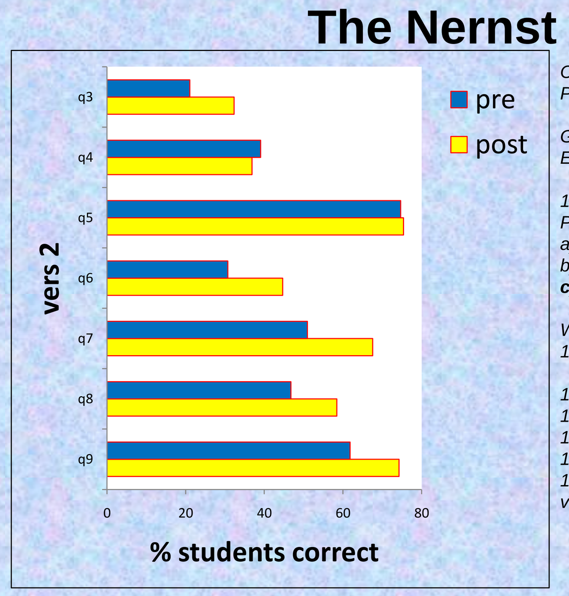
*5. T **F** — Q **increases** in the Nernst equation*

*6. **T** F — Q **decreases** in the Nernst equation*

*7. T **F** — Q **remains the same** in the Nernst equation*

*8. T **F** — water is not relevant to the reaction*

*9. T **F** — adding water does not change the Cu^{2+} ion concentration*



Consider the galvanic cell:

$Pb^{2+}(aq) + Zn(s) \rightarrow Zn^{2+}(aq) + Pb(s)$

Given the Nernst Equation:

$E_{cell} = E^{\circ}_{cell} - (2.303RT/nF) \log Q$

10. If a $Cl^-(aq)$ solution is added to the $Pb^{2+}(aq)$ to precipitate $PbCl_2(s)$, how will the voltage be affected?

a) Voltage stays the same

b) Voltage will increase

c) Voltage will decrease

Why?

*11. T **F** — adding Cl^- has no effect on voltage or redox processes*

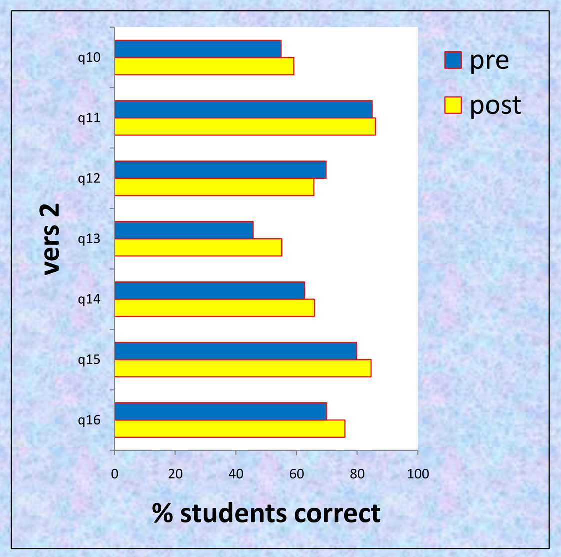
*12. **T** F — equilibrium shift to the left (reactants)*

*13. **T** F — Q **increases** in the Nernst equation*

*14. T **F** — Q **decreases** in the Nernst equation*

*15. T **F** — Q **remains the same** in the Nernst equation*

*16. T **F** voltmeter — the precipitate physically interferes with the readings*



Understanding:
- effects of adding water on voltage (q3) improved but is still low
- that water affects concentration (q9), but have trouble extending this to its affect on voltage
- effects of precipitating out a solute on voltage (q10) remained the same, and is significantly higher than the effects of water (q3)
- equilibrium (q4, q12) remained consistent, effects of precipitation (q12) is better understood than effects of adding water (q4)
- effect of the meaning of Q and of its effect on the Nernst equation (q5,6,7,13,14,15) either improved or remained consistent

In-Lab Observations

Safety procedures are followed (correct disposal of waste).

TA instructions strongly affected students' following of experimental procedures, such as rinsing and using tweezers.

Summary

- Students' scores improved from pre- to post-quiz, average learning gain of 0.237
- No pre-test effect apparent
- Improvement seen in redox, balancing eq.s, Galvanic cell notation, use of a reference electrode, and Q in the Nernst Equation
- Little improvement in electrochemical potential, Galvanic cells, concentration in the Nernst Equation, and definition of a reference electrode

Future Work

- Further statistical analysis
  - to confirm absence of pre-test effect
  - to test presence of differences between groups/sections
- Expert validation of questions
- Cross-tabulation of student responses to examine where individual answers changed
- Post-quiz student validation interviews
- Comparison to LG achievement from previous year