

USING METACOGNITIVE STRATEGIES TO IMPROVE STUDENT
PERFORMANCE AND CONFIDENCE IN
HIGH SCHOOL CHEMISTRY

by

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DEDICATION

I wish to dedicate this work to my parents, for always believing in me and giving me a proverbial splash of cold water every time I questioned my decision to undertake a master's degree.

I would like to especially acknowledge my father, John, who died after a long illness when I began this process in 2015. We may not have always seen eye-to-eye, but I could always count on his willingness to talk, his calmness, and, most importantly, his patience. I miss you, and I love you.

Finally, my mother, Virginia, who despite all the ups and downs of the past few years, has been a constant source of inspiration, love and support. Without her words of wisdom at the start of this journey, I would not have remained enrolled as a graduate student. Thank you. I love you.

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ABSTRACT

This action research investigated if using metacognitive reflection strategies in a high school chemistry class would increase student summative performance and confidence. Students were given a unit pre-test and a reflection in which they could assess their knowledge against the curriculum in a scaffolded manner. Students were surveyed before and after treatment to determine changes in student attitudes and perceptions of their abilities. Students were provided with a detailed breakdown of the curricular objectives for each question on the unit pre-test in order for them to make a study guide for themselves. It was found that there was an increase in mean score from pre-test to unit test, but performance on individual curriculum outcomes experienced extreme variation, both positive and negative. It was also found that student confidence decreased from pre-test to unit test when curriculum indicators were introduced to the students.

INTRODUCTION AND BACKGROUND

The City of Calgary is a large city nestled in the foothills of the Rocky Mountains in southern Alberta, Canada. Calgary's 1.2 million residents are served by two public school boards, Calgary School District No. 19 and the Calgary Roman Catholic Separate School District No. 1 (2016 Civic Census Results, 2016). Calgary School District No. 19 is the largest public school board in Calgary and second largest in Canada, with nearly 7,000 certificated teachers serving over 112,000 students (Calgary School District No. 19, 2015). The Calgary Roman Catholic Separate School District No. 1 has over 3,000 certificated staff serving over 52,000 students (Calgary Roman Catholic Separate School District No. 1, 2015). There are also six charter schools and over a dozen private schools operating within the city (Charter School List, 2015). All public and charter schools, as well as most private schools, are required by statutory law to follow the directives of the Minister of Education and implement the Alberta Education approved Program of Studies (School Act, 2015). In recent years Alberta Education has undertaken the revision all of provincial curriculum, from kindergarten through grade twelve (Guiding Framework, 2016).

Motivation for Action Research

The Guiding Framework (2016) seeks to transform Alberta's curriculum in to a practical document that sets clearly defined knowledge, skill and attitude outcomes that are easy for students, teachers and the general public to understand and interpret. It has also been made clear by Alberta Education that the methods used to assess students in the Province of Alberta will need to be updated to conform to a competency based

assessment approach. In 2014, while I was teaching junior high science, my employing school board moved from a percentage based assessment method to a four-point indicator model for students up to grade nine, inclusive. Students were assessed under different categories in each subject that generally related the curriculum to four broad categories: attitudes, knowledge and skills, evaluation, and societal links. The categories described expected curricular outcomes next to which an indicator of student performance was recorded. As an educator, I was initially hesitant to embrace this assessment model. However, after working with this assessment model for two full academic years, I came to rely on its precision to interpret the individual learning needs of my students. However, students and parents were left in the lurch struggling to understand how to interpret the new assessment data. I spent a lot of time explaining my assessments and grades to both parents and students. It occurred to me that, as an educator, I had left my students out of the loop in their own assessment. I knew where my students were with the curriculum, but my students had no clear picture of my expectations for them or where they stood in relation to the curriculum. I had begun to consider ways that I could improve student understanding of the curriculum when I was transferred from teaching junior high science to high school sciences.

When I was moved to a high school, I found it difficult to transition back to a percentage based grade book. I had difficulty clearly stating where my students were within the context of the curriculum and what their specific learning needs were. Further, I had fallen in to my old pattern of leaving students out of the loop when it came to what I expected of them and how they were assessed. It occurred to me that if I expected my

students to perform well when assessed against the curriculum then it was imperative for the students to know what I, and by extension the curriculum, expected of them.

Additionally, I reasoned that competency based assessment and reporting is where the curriculum in Alberta is heading, so it made sense to try and get a head start on it. These thoughts led me to the world of metacognition.

In simplest terms, metacognition is the awareness that a person has about what they do and do not know (Metacognition, 2001). In the context of my teaching high school chemistry, this meant I had to find a way to let students in on their assessment so that they could become aware of what they could do well and what required more effort on their part to improve. Further, I noticed that this lack of knowledge about curricular expectations led to student anxiety as, since they did not know what to study, they were unsure if they had all of the skills to be successful in class. It was these thoughts and observations that led me to my primary focus question for this classroom based action research project: *Will the introduction of metacognitive reflection strategies for studying improve student summative assessment scores in Chemistry 30?* An additional sub-question was investigated: *Will the introduction of metacognitive reflection strategies for studying increase student confidence in their ability in Chemistry 30?*

CONCEPTUAL FRAMEWORK

The idea of students actively participating in their own assessment may seem foreign to some educators. The traditional role of the classroom teacher has been to evaluate students on retention of presented information. This has led to students and teachers increasingly being evaluated through standardized test scores (Fischer, 2009). The

problem with this is that it leaves teachers and students out of the assessment equation. Rather than solely relying on imprecise tests to determine student knowledge, teachers need to engage students as active participants in their own education (Fischer, 2009; Guiding Framework, 2016). If students are not taught how to recognize gaps in their knowledge and what actions to take when the gaps are found, how can they be expected to successfully master any curriculum? Learning is an active process that is non-linear and requires the learner to incorporate knowledge and skills learned at different stages in their education to be successful (Fischer, 2009; Guiding Framework, 2016). One method through which students can become more adept at being active participants in their learning is through the application of metacognitive strategies in the classroom.

Metacognition

Metacognitive strategies are the means by which students monitor their abilities and evaluate skills associated with acquiring new knowledge (Rickey & Stacy, 2000). Metacognition also aids students in developing an awareness of the assumptions they make in their learning (Maclellan, 2015). Thus, metacognition is essential to improving student understanding as their assumptions are not always obvious to them; students can mistake past learning, experience, conjecture, and anecdotes for fact (Rickey & Stacy, 2000). Since the purpose of science education is to teach students how to evaluate and incorporate information when problem solving, it is imperative that students be taught how to identify and evaluate their assumptions (Davis 2003; Etkina et al., 2010). In order to do this, it is essential that students have a common framework and model from which they can be taught metacognitive skills. A possible method for such instruction is

through reflection, as reflection is a common means by which educators can develop and enhance student ability to understand and direct their own learning (Davis, 2003; Maclellan, 2015; White & Frederickson, 1998; Zepeda, Richey, Ronevich, & Nokes-Malach, 2015).

Metacognition through Reflection

The ability to reflect is a key skill for anyone intent on improving their understanding in a subject area (Bulu & Pedersen, 2010; Davis, 2003). Given the nature of science as an investigative process, reflection is a key tenet. However, not all students possess the ability to conduct meaningful reflections. Students with strong self-regulation skills incorporate a high level of metacognition into their learning while students that lack such skills generally fail to see the merit of any type of reflection (Davis, 2003; Schraw, Crippen & Hartley, 2006). Encouraging all students to reflect on their learning in science is therefore of critical importance. Students that regularly engage in reflective processes are more likely to recognize and acknowledge that their assumptions affect their understanding of a concept and are consequently more likely to work towards rational justification of their assumptions (Bulu & Pedersen, 2010; Etkina et al., 2010; Maclellan, 2015; White & Frederickson, 1998). To facilitate this, it is essential for educators to go beyond the traditional predict-observe-explain model and encourage students to focus on understanding where the information they receive comes from, show them how to assess its validity, and work out how the information fits in with their prior held beliefs (Schraw, Crippen & Hartley, 2006). In addition, students need to understand that to have true beliefs in scientific ideas and principles they must be able to reflect on

those beliefs and modify them to incorporate new information when it becomes available, even when it conflicts with prior-held notions (Maclellan, 2015). This process of constantly reflecting on beliefs and modifying them in light of new evidence is both reflective and representative of authentic science; it mimics the process of paradigm shifts in the scientific community where scientists engage in argument informed by evidence to promote systemic changes in hypotheses and theories (How Science Works, 2012). However, rather than scientists calling for modification of theories, it is students changing their own understanding of curriculum with new evidence evoked from reflective work.

Student metacognition and control of their learning increases as they become better able to reflect on and critique the information presented to them (Maclellan, 2015; Rickey & Stacy, 2000; Schraw, Crippen & Hartley 2006). However, such student metacognition does not occur in a vacuum. Students must be taught how to effectively reflect on their learning; instructing students on how to reflect is not a one-off event. It takes time to develop metacognitive awareness in students but, given its benefits, developing metacognitive awareness in students must be one of the main goals of teaching in general (Maclellan, 2015; Schraw, Crippen & Hartley, 2006).

Metacognitive Reflection Strategies

When students are taught how to plan, monitor, and evaluate their knowledge and skills they become better adept at identifying practical strategies to analyze and solve different types of problems (Rickey & Stacy, 2000; Zepeda et al., 2015). There are numerous strategies that have different outcomes for student metacognition, dependent

on which skills the students need to develop. As with any new activity students are likely to find difficult, scaffolding is an excellent method to introduce metacognitive reflection techniques (Bulu & Pedersen, 2010). To that end, starting with a highly structured and teacher-guided reflection and slowly moving towards a less structured method gets students used to the idea of engaging in reflective practices. These scaffolded reflective exercises may be broken into two categories: general prompt and specific prompt (Bulu & Pedersen, 2010; Davis, 2003).

Generalized Reflections

In generalized reflection students are given open-ended prompts on which to reflect with no hint at the expected final product (Davis, 2003). This type of activity requires students to draw on their prior learning and integrate it in the moment. The benefit of this is that it allows the students to state their exact thinking at the moment the reflection was completed. Further, since students must integrate past knowledge into the present moment to complete a response to a generalized reflection prompt, it helps students to recognize and confront their prior held beliefs (Bulu & Pedersen, 2010; Davis, 2003). This makes students more critical of the evidence they elicit to support their thinking. However, students must be shown how to do this at a metacognitive level (Schraw, Crippen & Hartly, 2006). When students are explicitly taught that learning is an investigative cycle where reflection is a critical component, they become more accustomed to critiquing their work and the work of others in an open forum (White & Frederickson, 1998). By scaffolding these critiquing tasks students can be shown how to identify and use scientific thinking processes (Etkina et al., 2010; Maclellan, 2015). This

notion applies to school laboratory activities as well. By using open-ended inquiry methods that have general targets, students become more critical of the evidence they collect and begin to view their peers as collaborators to bounce ideas off of rather than as checks to see if they got the right answer (van Opstal & Daubenmire, 2015). However, there are times where reflection is best scaffolded with specific prompts that have an intended outcome rather than open ended, generalized prompts.

Specific Reflections

Scaffolding with specific reflection prompts can help point out to students the most important ideas from curriculum (Bulu & Pedersen, 2010). The need for specific prompt scaffolding is further reinforced when one considers that students who are unable to self-identify misconceptions and problems in their understanding are less likely to critically evaluate any ideas or information presented to them as they believe they already have a firm understanding of the material (Davis, 2003). By having students explain how or why something works using ideas and terminology from the course, teachers can easily identify major misconceptions without the need to sift through generalized reflections looking for evidence of understanding, or lack thereof. Further, scaffolding with specific reflection prompts allows for the easy introduction of context-specific hints and expert information (Bulu & Pedersen, 2010; Davis, 2003). This helps students to improve their understanding of the concepts being taught and further encourages them to carefully consider all information presented to them. Further, problem solving skills improve with specific scaffolding as students seek not to memorize formulae but rather assess if they

have sufficient information to provide a meaningful solution to a problem (Ricky & Stacy, 2000).

METHODOLOGY

The conceptual framework describes current research stating that when students are taught how to actively reflect on their learning, it leads to improved outcomes on summative assessments and increased student confidence in their abilities when assessed against curricular objectives. This action research focused on determining the impact of using guided reflections coupled with unit pre-tests to determine if there was an effect on student performance on summative unit assessments. The effect of student confidence with chemistry was also assessed using student surveys and student interviews with the teacher to gain insight on student views of using metacognitive reflection in the classroom.

Treatment Description

Treatment for this study began with teaching students how to read curriculum documents and providing students with the Student Curricular Objectives sheet, which described in clear language the curricular outcomes against which students were assessed (Appendix A). Students were shown how to locate the publically available curriculum documents and their general structure was explained to them over 30 minutes. The curriculum document links to the curricular objectives sheet was explicitly stated. Further, a practice unit test (Appendix B) and a final unit test (Appendix C) that clearly indicated which curricular outcomes were being assessed was given to students in succession at the end of Unit B: Electrochemical Changes. Students were provided with

guided reflection sheets (Appendix D) given when the unit pre-test was administered (Appendix B) to help them make a personalized study guide for their unit test. Student attitudes towards objectives based studying was collectively gathered pre- and post-treatment using the Student Attitude Survey (SAS), administered through the students' school-district provided Google accounts (Appendix E). Nine students were selected for personal interviews with the teacher where more in-depth questions were asked (Appendix F) The treatment was introduced in Chemistry 30 - Unit B: Electrochemical Changes; a grade twelve general chemistry course utilizing the Alberta Chemistry Program of Studies. Data collection began at the start of the course in February, 2017 and was completed at the end of March, 2017.

At the conclusion of Unit B: Electrochemistry, results from all instruments was collectively analyzed to triangulate data to answer the research question and sub-question, as shown in the Data Triangulation Matrix (Table 1). Data from both SAS were compared with the results of both the pre- and unit-tests. Student responses on the SAS were analyzed against the summative assessment data to determine if student perceptions were in line with actual performance. Student interview responses were compared to summative assessments in the same manner. Further, teacher observations, which were recorded in writing throughout the project, were compared with student attitude data and summative assessment results to determine if the teacher perception was in line with student perception and assessment data. A high emphasis was placed on looking for both consistencies and inconsistencies across all data collection instruments.

Table 1
Data Triangulation Matrix

Research Questions	Data Collection Tools		
<u>Primary Question:</u> Will the introduction of metacognitive strategies for studying improve student summative assessment scores in high school chemistry?	Pre <i>and</i> post unit Student Attitude Survey	Unit pre-test <i>and</i> unit test scores	Student Interviews
<u>Sub-question:</u> Will the introduction of metacognitive strategies for studying increase student <i>confidence</i> in their ability in high school chemistry?	Pre <i>and</i> post unit Student Attitude Survey.	Teacher Observations	Student Interviews

Consent, Assent and Ethics Approval

Prior to treatment, students were informed of the nature of the study and provided informed consent forms, which were required to be returned to the researcher with the signature of the students legal guardian, if the student was under eighteen years of age, or the signature of the student themselves, if the student was over eighteen years of age. Informed assent forms were also collected from students under the age of eighteen such that both the student and their parents, if they were under age eighteen, had the right to withdraw from participating in the action research project. The information of students who did not return informed consent and/or assent forms or who withdrew their informed

consent/assent was not included in this study in keeping with local school board policies and established principles for sound educational research. Fifty-one students out of 67 total students in two Chemistry 30 classes participated in this study.

The research methodology for this project received an exemption from Montana State University's Institutional Review Board and compliance for working with human subjects was maintained (Appendix G). Further, this research methodology received ethics approval that complied with the Canadian Tri-Council Policy Statement (TCPS 2): Ethical Conduct for Research Involving Humans from the local school jurisdiction in Alberta, Canada where the research was conducted.

Data Collection Strategies

Treatment began in Unit B: Electrochemistry. This was the first unit taught in the Winter 2017 academic semester, commencing February 1, 2017. Students were given an initial lesson on how to read the Program of Studies for Chemistry 30; the curriculum document provided by the Alberta Ministry of Education. Students were provided with a sheet titled Student Curricular Outcomes (SCO) that outlined the requirements of the electrochemistry unit directly from the Program of Studies, but re-written for clarity to students (Appendix A). It was explained to students that all assessments in this unit, inclusive of the unit test, would be based on the items listed on the SCO sheet. Further, it was made clear to students that they would not be assessed on things that were not explicitly listed on the SCO sheet though outcomes that were on the sheet could be combined and assessed simultaneously. Students were also told that some class time

would be devoted to focusing their studying for the unit-test, utilizing the outcomes they were provided with.

Before Unit B: Electrochemistry began, students were given the Student Attitude Survey (SAS) (Appendix E). The SAS was a Likert-scale questionnaire completed through the students' school-district provided Google account. The survey required students to answer all questions on a four-point scale where one represented *always*, two represented *sometimes*, three represented *rarely* and four represented *never*. The survey questions were broken in to three categories. Category 1 (questions 1-3) focused on student use of feedback in their learning. Category 2 (questions 4-8) asked students to rate their study habits. Category 3 (questions 9-11) gauged student confidence in their abilities against curricular objectives. Student responses to each of the Likert-scale questions were analyzed for percentage of responses in each response category, for each question, and recorded for later comparison to the post-unit SAS, which was identical to the initial SAS. A normalized gain calculation was completed for each question on the survey to compare the initial SAS with the final SAS (Hake, 1998). Testing conditions were maintained while the survey was implemented to help ensure that students did not feel pressured to discuss their thoughts or share their responses with their peers until after the survey was submitted.

After the final SAS was administered, nine students were selected by the teacher for in-depth interviews, utilizing the Student Interview Questions (Appendix F). The students were selected based on their current grade in the course and having the required consent/assent paperwork on file. Three students with cumulative grades in chemistry at

or above 85%, three students between 55% and 85%, and three students below 55% were selected across two classes. This was done to ensure that a wide variety of student abilities and knowledge levels were represented in the interviews. Students were asked to volunteer to answer the questions; students at the grade levels stated above volunteered in sufficient number such that the teacher did not have to ask students to participate. Students at each level were selected on a first-come basis. The questions in the Student Interview were designed to elicit student thoughts, feelings and opinions on using curricular objectives to guide their learning and studying (Appendix F). Student responses were analyzed for general trends, thoughts, attitudes and ideas as they related to using feedback to guide their own learning, using unit pre-tests as a study tool, and confidence with the chemistry curriculum expectations. Student responses were recorded on paper, in point form, by the teacher as the student responded. Students were shown the point form notes taken after each question and asked if what was written was an accurate representation of their response. If the student indicated that the point form notes were not accurate, the teacher and student edited them together until the student felt the recorded response was sufficient. No personal identifying student information was recorded during the interviews. Students were not provided a copy of the questions in advance.

After the initial SAS was administered, instruction and coursework began for Unit B: Electrochemical Changes. The unit was taught as it was in past semesters, with the exception that the curricular objective(s) for all tasks, assignments and quizzes were explicitly stated to students prior to being implemented. Students were also encouraged

to track their understanding of each outcome using the Student Curricular Outcomes (Appendix A) sheet provided at the start of the unit, though student self-tracking of their progress was not included as part of this study.

At the end of the unit, a pre-test was given in-class under regular testing conditions (Appendix C). The purpose of the pre-test was to have students see for themselves what their ability level was compared to the outcomes on the SCO sheet. The pre-test had multiple choice and numeric response questions, each of which was coded to one or more curricular outcomes. The coding for the curricular outcomes was the same as those on the SCO sheet. The pre-test was machine scored using Smarter Marks and the results returned to the students in the same class that they wrote the pre-test (Smarter Marks, 2015). Student scores were recorded and aggregated by curricular outcome, showing mean and median responses to questions under each assessment category, utilizing the Smarter Marks scoring program (Smarter Marks, 2015). Scores were analyzed for common themes and mean response rates to identify class-wide misconceptions. Further, aggregate data for all classes was analyzed for mean overall score and mean correct response for each curricular outcome on the pre-test.

Students completed the Student Reflection Sheet during the pre-test (Appendix D). The reflection sheet contained spaces for students to write down which questions on the pre-test they experienced difficulty with such that they would end up with a reference sheet of what they needed to review. Space was also provided for students to reference worksheets and their textbook so that they would have a map of where to get extra information for review and/or practice. There was a two-class spacing, which included a

weekend between the two classes, from administration of the pre-test (Appendix B) and administration of the unit test (Appendix C) to allow students time to review and ask questions. Like the pre-test, the unit test was broken down by knowledge outcome, however the knowledge outcomes were not printed directly on the unit test as it was thought it may distract students from expressing their knowledge because they would be too focused on which curricular objective was being tested. However, the student response sheets were coded to allow for curricular outcome comparisons with the unit pre-test. Students were provided with a breakdown of how they performed under each curricular objective when their tests were returned to them.

After the unit test was completed, student scores were aggregated utilizing the Smarter Marks program (Smarter Marks, 2015). The scores were analyzed for mean and median correct response rates for each curricular outcome category. This information was compared with the results of the Pre-Test and analyzed for persisting misconceptions from Pre-Test to Unit Test. Further, the aggregated results of the Pre-Test and Unit Test were compared using a normalized gain calculation. The main focus of the analysis was to determine if there were any normalized gains in student performance from pre-test to unit-test. Both the pre-test and unit test data were visually compared to each other using a box-and-whisker plot.

DATA AND ANALYSIS

The study began with the administration of the first Student Attitude Survey (SAS) ($N=51$). The survey questions were associated with three different categories: student use of feedback (questions 1-3), student study habits (questions 4-8) and student

confidence with the curriculum (questions 9-11). The results of the initial SAS show that 96% of students felt that they always or sometimes use the feedback given to them in class to help inform what they need to study (Figure 1). This compares to 93% responding always or sometimes in the post-exam administration of the SAS. Ninety-four percent of students reported feeling that they understood what the curriculum required of them compared to 91% on the post-exam survey (Figure 1). It should be noted that the percentage of students reporting that they always understood what the curriculum required of them dropped from 41% to 30% from the pre-exam survey to the post-exam survey (Figure 1), representing a normalized gain of -0.18 (Table 2). This is consistent with student interview responses. All nine students that were selected for an interview reported that they felt less certain of the curriculum, despite having the student outcomes provided to them. One student in particular remarked that, “I thought I knew everything that I was supposed to know but the outcomes sheets showed me that there is a whole lot more to chemistry than just knowing how to do a type of question.” There was an exception to the general trend of positive responses for the first section on question three: unit pre-tests help me study for unit tests. Thirty-three percent of students reported on the initial quiz that unit pre-tests rarely or never help them prepare for unit tests compared to only five percent reporting that pre-tests never helped them study on the post-unit exam survey (Figure 1). This represents a normalized gain of -0.59, indicating a shift in student perception of the role of pre-testing (Table 2). A normalized gain of 0.32 and 0.15 for the positive responses “always” and “sometimes” respectively, complimented the downward trend in negative responses to question three (Table 2).

Eight of the nine students interviewed agreed that the unit pre-tests were helpful. It was remarked that, “The unit pre-tests really helped me to understand where I needed to focus my studying. Sometimes I would spend a lot of time reviewing things I already knew and avoiding things I didn’t like to do. Now I know that if I want to do better I need to work harder on the things I don’t understand.” One student that did not like the unit-pretests remarked that, “They feel just like another test, and they make me nervous.”

These results are also consistent with my classroom observations of the students. I made several notes indicating that students were more mindful of the curricular objectives. Further, after the first unit pre-test, fifteen students in one class asked if unit pre-tests would be done for every unit. I neglected to record the number of students in my other class that asked similar questions of the pre-test; the questions were asked though it is unknown how many times.

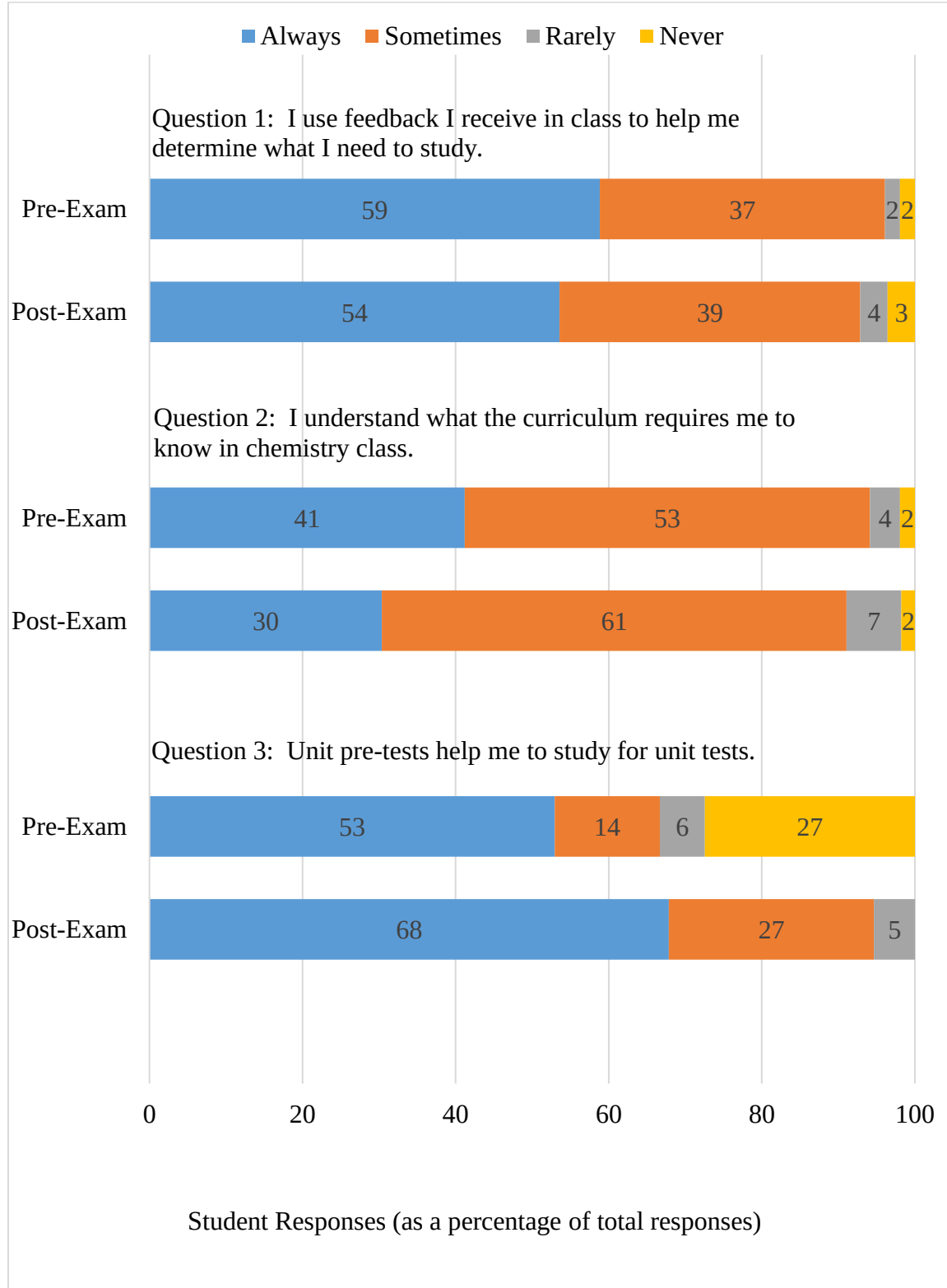


Figure 1. Student attitude survey pre-post comparison, questions 1-3, (N=51).

Table 2

Normalized Gains from Pre- to Post-Unit Student Attitude Survey

Student Attitude Survey Question	Normalized gains per answer type			
	Always	Sometimes	Rarely	Never
1. I use feedback I receive in class to help me determine what I need to study.	-0.13	0.03	0.02	0.02
2. I understand what the curriculum requires me to know in chemistry class.	-0.18	0.17	0.03	0.00
3. Unit pre-tests help me to study for unit tests.	0.32	0.15	-0.01	-0.38
4. The unit pre-test reflection sheet was useful.	0.12	0.23	0.11	-0.59
5. I used the unit pre-test reflection sheet to guide my studying for the unit test.	-0.05	0.36	0.09	-0.54
6. The unit pre-test reflection sheet helped me to target my studying to skills that I needed to improve.	-0.04	0.38	0.05	-0.54
7. The unit pre-test increased my confidence going in to the unit test.	-0.01	0.34	0.09	-0.51
8. Unit pre-tests make me aware of what I do and don't know in Chemistry 30.	0.25	0.26	0.02	-0.59
9. I feel more comfortable about chemistry because I know more about the curriculum expectations.	-0.04	0.23	-0.07	-0.02
10. Knowing which curriculum outcomes I am responsible for has made me more confident in chemistry.	-0.22	0.26	-0.07	-0.02
11. I am aware of the things I do know and what I do not know in chemistry.	-0.14	0.16	0.01	-0.02

The second section of survey questions (questions 4-8) dealt with student study habits and showed significant reductions in negative responses from the initial to the final SAS (Figure2). Fifty-nine percent of students initially thought the pre-test reflection sheets would be useful compared to 84% on the final SAS. This represents a normalized gain of -0.54 for the answer “never” and 0.38 for the answer “sometimes” (Table 2). Similar trends were noted for an increase in using the pre-test reflection sheet to guide studying

for the unit test, and increase in student confidence going in to the unit test (Figure 3, Table 2). There was a notable uptick in students reporting that pre-tests made them more aware of what they do and do not know in chemistry (Figure 3). A normalized gain of 0.25 and 0.26 for the positive “always” and “sometimes” answers, respectively, was noted (Table 2). This was the only question on the SAS in which an increase in the “always” response was recorded. Unlike the previous question group, there were no substantial decreases in response rates for the “always” response and there were significant normalized gains in the “sometimes” response for all questions in this group (Table 2).

The student interviews revealed similar trends. When asked if the curriculum indicators guided their studying, one student responded, “If there was no pre-test I probably would not have looked at the [curriculum outcomes sheet] you gave us but the pre-test made me have to look at it.” When asked specifically if the pre-test gave them a better awareness of what they do and do not know in relation to the curriculum, all nine students responded in the affirmative. One student responded, “I thought I had enough understanding to get a 50% but the pre-test made me see that I didn’t know as much as I thought I did. I wasn’t surprised when I failed the unit test because I knew I didn’t study enough to pass it.” Another striking student response was “I knew that I was doing okay but the pre-test really helped me see what areas needed more focus when I was studying.” I noted a similar, general trend in the classroom when returning the pre-test scores. A lot of students seemed genuinely surprised that they did not do as well as they expected but were grateful that the pre-test was not a summative assessment. For the two classes

between the pre-test and the unit test, there was a notable increase in students asking questions that related to specific parts of the curriculum.

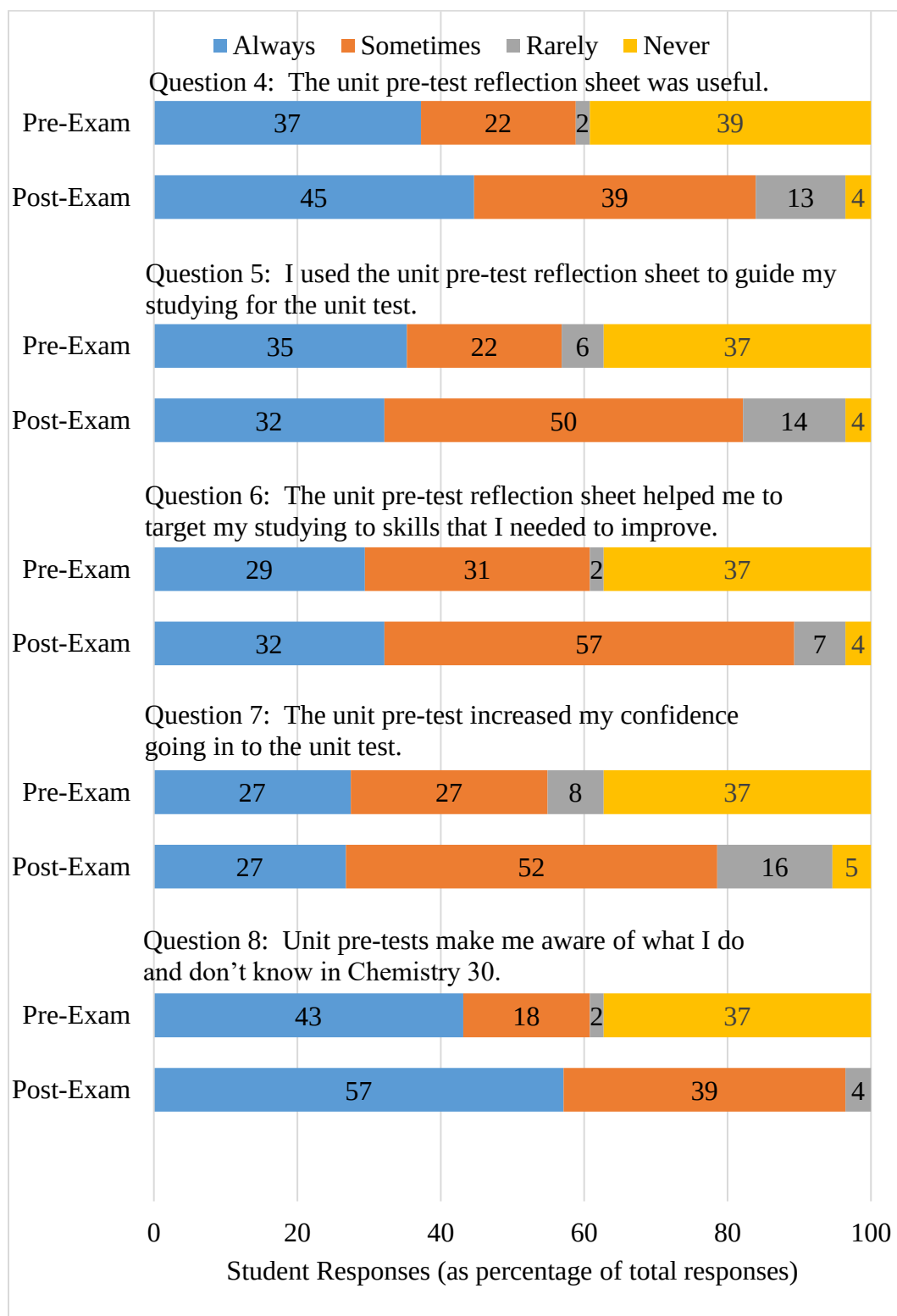


Figure 2. Student attitude survey pre-post comparison, questions 4-8, (N=51).

The third section of survey questions (questions 9-11) centered on student confidence. Overall, the response rates remained relatively consistent for the negative response types, “rarely” and “never” (Figure 3). This is also reflected in the marginal normalized gains for these questions (Table 2). The response rates from the initial to the final SAS remained relatively unchanged for student comfort level with chemistry. When taken with the decrease in “always” answers of 31% to 16% for curricular outcomes making students feel more confident in chemistry, student confidence in chemistry has not changed much overall but knowledge of the outcomes makes them less certain in their abilities (Figure 3). There was also a shift from the initial to the final survey of student awareness of what they do and do not know in chemistry, with those stating “always” decreasing by 7% and those stating sometimes increasing by 8% (Figure 3). This is consistent with the normalized gain of 0.16 for the “sometimes” answer for question 11 (Table 2).

The students who were interviewed also echoed the results found with this section of the SAS. One student remarked, “I know what I need to study but I do not know where to start with it.” Another student remarked that it was, “Nice to have the pre-test reflections but they would be good with other assignments and quizzes too. Can we have the outcomes sheet with us when we do quizzes next?” The latter statement was echoed by another student stating that they, “Wish there was more reflection in the unit so I could start earlier reviewing what I am not understanding.” Overall, I noted that some students were eager to use the reflections while others were indifferent. One student was hostile to the unit pre-test, stating, “It was a waste of [their] time.”

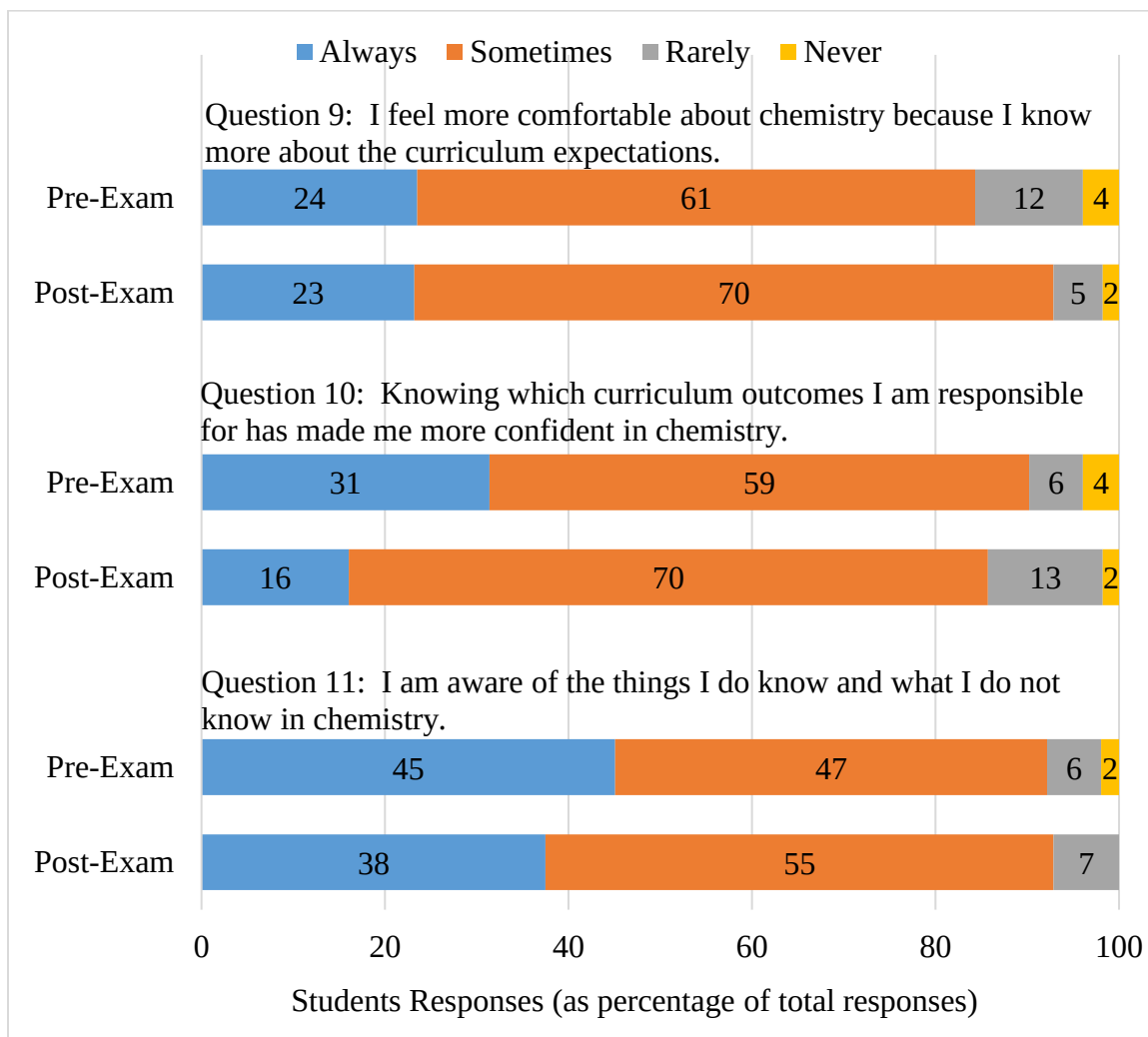


Figure 3. Student attitude survey pre-post comparison, questions 9-11, (N=51).

The results of the unit pre-test to the unit test show an increased median from 68% on the pre-test to 75% on the unit test (Figure 4). The upper and lower quartile ranges of the pre-test fall within and below the lower quartile range for the unit test. The lower quartile range for both the pre-test and unit test spans a greater range of scores than the upper quartile ranges in both data sets. The minimum and maximum values, excluding outliers, were 37% and 84%, respectively, for the pre-test (Figure 4). There were no data outliers for the unit test, with minimum and maximum scores of 37% and 4%,

respectively (Figure 4). Two students participating in the study did not complete the unit pre-test and their scores have been omitted from this study. The average normalized gain for students, as a whole, from the unit pre-test to the unit test is 0.27.

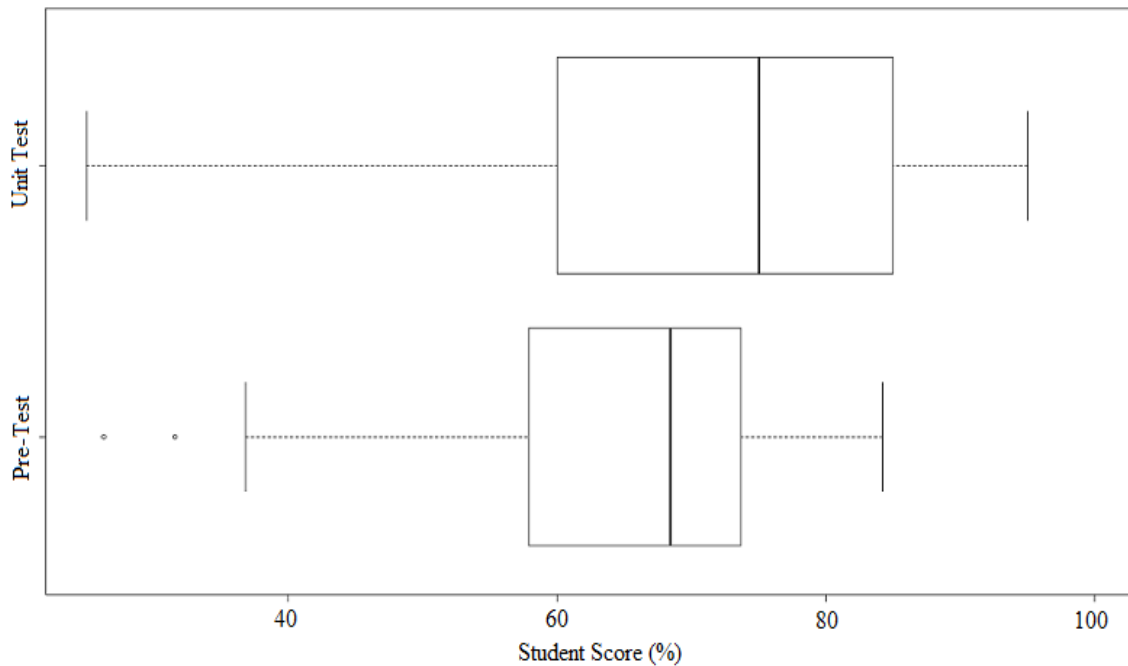


Figure 4. Comparison of unit pre-test and unit test scores, (N=49).

In terms of averages, outcome K1C saw a 40.82% increase in average score from pre-test to unit test, outcome S2C saw a 20.41% increase and outcome K2B saw an 18.37% average increase. Outcome K2E saw the greatest average decrease at -31.63% from pre-test to post test. Outcomes K1E, S1B, S1F, and S2A also saw decreases of -10.20% to -14.29% (Table 3). Hake (1998) defined the normalized gains of less than 0.3 to be low, 0.3 to 0.7 as medium, and higher than 0.7 as high. Using Hake's (1998) definition of 0.3 or lower as an insignificant normalized gain, six of fifteen outcomes saw no appreciable change from pre-test to post-test: K1B, K2C, K2E, S1A, S1D, and S1G. This represents three of seven knowledge (K) outcomes and three of eight skill (S) outcomes. (Table 2).

Seven of fifteen outcomes saw moderate normalized gains. Three were positive: K1C, K2B and S2C. Four were negative: S1B, S1E, S1F, S2A (Table 2). All four areas with moderate but negative normalized gains were for skill based curricular outcomes. Three of fifteen outcomes saw high normalized gains, all negative: K1A, K1E and K2E (Table 2).

Table 3
Differences per Curricular Outcome

Curricular Outcome	Average Score Difference (%)	Normalized gain
K1A	-2.04	-1.00
K1B	-2.04	-0.11
K1C	40.82	0.61
K1E	-14.28	-1.75
K2B	18.37	0.64
K2C	-6.80	-0.28
K2E	-31.63	-0.89
R1C	-5.10	-0.19
S1A	0.00	0.00
S1B	-10.20	-0.38
S1D	-6.12	-0.30
S1E	-6.12	-0.60
S1F	-12.25	-0.55
S1G	1.02	0.03
S2A	-14.29	-0.36
S2C	20.41	0.48

INTERPRETATION AND CONCLUSION

The data presented in this paper supports the idea that when students are taught how to monitor their learning in chemistry, their summative assessment scores improve. However, summative score improvements across all curricular outcomes were not uniform. In some instances, student performance decreased. Overall, it was noted that

reflection is a reliable method to use when teaching students to evaluate their understanding of curricular concepts through scaffolded reflection.

Scaffolded Reflections

By scaffolding reflection, namely in the form of a pre-test reflection sheet, students in my chemistry classes were able to see for themselves which parts of the curriculum they had a rigorous understanding of which parts required further improvement. This supports the idea that student performance can improve when they receive deliberate instruction on reflective practice in a scaffolded manner (Maclellan, 2015; Bulu & Pedersen, 2010). This was supported by the final SAS in which students indicated that they were more aware of the concepts they did not know thoroughly after they were required to complete a pre-test and evaluate their understanding against curricular outcomes. The majority of the nine student interviewed stated that they liked the use of the reflections for the pre-test and would have liked to have had more reflections throughout the unit. However, two students indicated that they did not appreciate the reflections or the time utilized in class to complete them. It is possible that these students did not see the value in reflecting on their learning and may require additional scaffolding and instruction on metacognitive practices in order to be able to use reflection as a tool in their learning. This lends support to the idea that the instruction of metacognitive practices must be deliberate, regular, and repeated in order to develop appreciation of reflection and to develop student skill in employing it over time (Schraw, Crippen & Hartley, 2016).

This effectiveness of guided reflection was further supported by the increase in median test score and improved quartile ranges on the unit-test compared to the pre-test.

The bottom end of the lower interquartile range increased from 58% to 60% from pre-test to unit-test and the upper end of the top interquartile range moved from 73% to 84%.

An extension of this research would be to investigate if this increase in overall student performance also applies to smaller assignments and quizzes. I did note early on that it may be beneficial to be more deliberate in using the curricular outcomes to refer to all assignments and activities in class, potentially in a student journal. As the Province of Alberta moves closer to an outcomes based curriculum, it would also be prudent to investigate different methods of tracking student progress against all curricular outcomes over an entire course, not just at unit test time. Implementing a more rigorous reflection practice in the classroom may also help students develop a deeper appreciation for, and understanding for the necessity of, reflecting on their own learning.

Student Confidence

In regards to student confidence, the SAS shows an overall decrease in student confidence from pre-test to post-test. This result was unexpected. However, when coupled with the student interview responses, one possibility became clear: students may show a decreased confidence as they recognize that the curriculum is more rigorous than they expected and as students realize that their understanding of the curriculum is not as thorough as they thought. This is consistent with the idea that until misconceptions about their understanding are explicitly pointed out to them, students may ignore the evidence that they have a less rigorous understanding of the curriculum than they think they do (Rickey and Stacey, 2000). It would be a worthwhile future endeavor to investigate how student confidence decreases and to see if there is an increase in student confidence as

they become more adept at assessing their own understanding against the curriculum. IF there were an increase in student confidence over time, it would lend additional support to the idea that as students better monitor and evaluate their learning, their confidence and summative performance would improve (Maclellan, 2015; Schraw, Crippen & Hartley, 2016). It would also be useful to look in to different methods for scaffolding student reflections with the curriculum until they become proficient enough to do so on their own.

Based on my classroom observations of my students over the course of this action research, I did notice that students' confidence decreased when their pre-tests were handed back. Many students expressed dismay as they thought they had performed better than their score indicated. It would be interesting to investigate if including more curricular reflections on smaller assignments, quizzes, and practice work would help students increase their confidence leading up to the pre-test and unit test. This would also tie in to assessment as it would provide the students and their teacher with a greater understanding of where students are in relation to curriculum allowing for a more holistic evaluation of students.

Student Summative Performance

The area from this research that requires the most follow-up is in relation to student performance when evaluated against individual curricular outcomes. There were noticeable increases in student comprehension of the same curricular outcomes from pre-test to unit test. However, there was not a uniform increase in student performance across all curricular outcomes. Six of fifteen outcomes analyzed saw no significant

change when using Hake's (1998) normalized gains analysis. Three saw positive gains and five showed negative gains. It is interesting that while overall student performance increased as an average, there were significant positive and negative deviances on individual curricular outcomes from pre-test to unit-test.

The three outcomes which saw the greatest positive normalized gains were K1C, K2B and S2C. These outcomes were also explicitly reviewed in class between the pre-test and the unit-test. The remainder of the class time between the two assessments was devoted to individual student review time. Was the time spent reviewing the outcomes which saw improvement from pre-test to unit-test the reason for the increase in student performance? Could it be that students thought that since time was spent on these three outcomes that they would be more heavily emphasized on their unit-test? Reflecting back on the time in class between the two assessments, I believe that I could have done a better job of explicitly stating why we were reviewing some outcomes and not others. This would have likely reduced any confusion the students had on we used class time for some curricular objectives and not others. Further, it would have been useful to develop a guide of where to locate information on specific curricular objectives across all resources available to the students: their textbooks, their in-class workbooks, past assignments and quizzes, and internet resources. This would have helped students further focus their studying and assist those students who stated they had difficulty knowing where to begin with the information they wrote in their reflection sheets on the pre-test.

In the future, it would be prudent to look at pre-tests and unit-tests to determine if there is variation in the difficulty of the questions being asked, if time constraints are a

factor, or if the act of formal testing has an impact on student performance. Further, the unit pre-test focused only on the curriculum outcomes shown in Table 3 while the unit test had additional outcomes and written response questions. This makes direct comparison less reliable although, in this study, this discrepancy was unavoidable; it was necessary to balance the school science department need for common assessments with the desire for more data on student performance against curricular outcomes. The more relaxed nature of the pre-test may also have played a role and merits further investigation. The unit test was an internal, department developed, common assessment. Although the unit test scores reported in this paper were adjusted to include only those indicators common to the pre-test and unit test, the added workload of the unit-test overall coupled with the more high stakes atmosphere of a unit-test may have skewed student performance.

VALUE

This process has been a valuable professional learning experience. It has allowed me to start the process of including my students in their own evaluation and assessments in a meaningful way. Rather than just reporting scores to students, I now have them assess what they did well and what they could have done better. I have already noticed that if I do not allow time for even a brief reflection on student work in class my students will remind me to do it and, if necessary, demand it. I have found it is best not to fight this; if the students are asking for a chance to review their standing against the curriculum, then I see it as a benefit to them and myself, as promoting strong self-regulation skills is one of my main goals as an educator. If the students have a better understanding of where they

stand, it ultimately makes my job a lot easier. It makes it easier for me to diagnose and prescribe interventions that best meet the needs of individual students and is a practical way by which I can implement more differentiated instruction in to my practice. Further, this project has brought me closer to my goal of ensuring that my students are actively involved in their own assessment. Ultimately, I want my students to be able to describe their learning to the same degree that I can, or better. I realize that this may not be possible to do with all students, but it is a goal that I will continue to strive towards. This will also aid me in ensuring that I focus on improving student confidence in addition to their academic performance. I now recognize that I need to put more deliberate effort in to ensuring that students feel sufficiently prepared to tackle summative assessments. Perhaps more formative assessments in class, coupled with the reflection practices discussed in this paper, would lead to higher student confidence? This is a worthwhile question to answer and I intend to pursue it over the remainder of the current academic semester and in to the future. I know my students have discussed their confidence with their peers in my colleague's classes. This has led to my colleagues approaching me to further inquire about the nature of my project.

The professional conversations that the completion of this action research project have led to have been invaluable. These conversations have allowed me to understand the opinions and viewpoints of my colleagues. It has also made it easier for me to broach difficult topics, such as altering departmental common assessments, as I have been able to take a data based approach. While difficult conversations have been had regarding departmental common assessments, I have found my colleagues are very responsive to

data driven comments. It has also given me the courage to ask tough questions of my colleagues, such as requesting pedagogical reasoning behind their professional approaches to assessment as well as to respond to tough questions asked of me. I have found that when I am more knowledgeable about the motivations for my actions in the classroom, I become a more effective educator and a more valuable colleague to my peers. This process has also led to me having pedagogical discussions with colleagues outside of the science department, and colleagues at other schools.

The act of discussing pedagogy with colleagues outside of my regular teaching assignments is beginning to make an impression on me. As educators, we spend so much time working in isolation that it can be difficult to discuss important concepts such as student involvement in assessment and metacognitive practices. Such conversations become overshadowed by more immediate, though I would argue less important, aspects of daily life in a school. Because of the action research process, I now recognize how important it is to have regular, scheduled professional learning communities in a school. I have discussed completing a department action research project with my Science Learning Leader and he seems quite receptive to the idea. As we look for new ways to bring teachers together, implementing teacher driven action research at the school level, or even between schools, may be a way to bring teachers together in a meaningful way.

As a final thought, this process has shown me that outcomes based assessments can provide enormous value to the classroom teacher. However, implementing outcomes based assessments will be a challenging task. It is not a simple matter of Alberta Education or school boards requiring teachers to report student performance against

curricular outcomes. First and foremost, teachers would require additional training.

However, for meaningful professional development teachers would need to see the value in outcomes based assessments and reporting. Careful consideration would need to be given on how best to achieve teacher understanding. Increasing teacher consultation prior to implementing such a change in reporting, and providing a formal mechanism through which teachers can register difficulties and suggestions for improvement, would go a long way towards making such a transition easier.

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APPENDICES

APPENDIX A
STUDENT CURRICULAR OUTCOMES

STUDENT CURRICULAR OUTCOMES

Chemistry 30 – Unit B: Electrochemical Changes

KNOWLEDGE OUTCOMES

K1. Define and describe oxidation and reduction reactions in solutions

- ☐ A. define *oxidation* and *reduction* in terms of what is expected to be seen in at the macroscopic level as well as explain, at the theoretical level, the movement of electrons in these reactions
- ☐ B. define *oxidizing agent*, *reducing agent*, *oxidation number*, *half-reaction*, *disproportionation*
- ☐ C. predict the spontaneity of a redox reaction, based on standard reduction potentials, and compare their predictions to experimental results
- ☐ D. describe how physical coatings and cathodic protection are used to prevent corrosion
- ☐ E. identify electron transfer, oxidizing agents and reducing agents in redox reactions that occur in living systems (e.g., cellular respiration, photosynthesis) and in corrosion

K2. Apply the principles of oxidation and reduction to electrochemical cells

- ☐ A. define *anode*, *cathode*, *anion*, *cation*, *salt bridge/porous cup*, *electrolyte*, *external circuit*, *power supply*, *voltaic cell* and *electrolytic cell*
- ☐ B. identify the similarities and differences between voltaic cells and electrolytic cells
- ☐ C. predict and write the half-reaction equation that occurs at each electrode in an electrochemical cell
- ☐ D. recognize that predicted reactions do not always occur (e.g. chloride anomaly)
- ☐ E. identify the products of electrochemical cells
- ☐ F. explain why measured cell potentials are not always equal to their theoretical (calculated) values
- ☐ G. explain that the values of standard reduction potential are all relative to 0 volts, arbitrarily set as the hydrogen electrode at SATP

SKILL OUTCOMES

S1. Write equations for redox reactions and compare them to other types of chemical reactions.

- ☐ A. use half-reactions and/or oxidation numbers to differentiate between redox reactions and other types of reactions
- ☐ B. compare the relative strengths of oxidizing and reducing agents, using empirical data
- ☐ C. use half-reaction equations obtained from a standard reduction

potential table to write equations for and balance redox reactions in neutral and acidic solutions

- ☐ D. write simple half-reaction equations from information provided about a redox chemical reaction and use the information to balance equations under neutral and acidic conditions
- ☐ E. assign oxidation numbers to the chemical species undergoing reduction and oxidation and use oxidation numbers to balance reactions under neutral and acidic conditions
- ☐ F. use a standard reduction potential table as a tool when considering the spontaneity of redox reactions and their products
- ☐ G. perform calculations to determine quantities of substances involved in redox titrations.
- ☐ H. Solve stoichiometric problems related to redox titrations

S2. Make general predictions about, perform calculations related to, and construct/model electrochemical cells.

- ☐ A. calculate the standard cell potential for electrochemical cells
- ☐ B. predict the spontaneity of redox reactions, based on the relative positions of half-reaction equations on a standard reduction potential table and/or standard cell potential
- ☐ C. calculate mass, amounts, current and time in single voltaic and electrolytic cells using Faraday's law and stoichiometry.
- ☐ D. construct and observe electrochemical cells in a laboratory setting

REASONING OUTCOMES

R1. Design experiments relating to redox reactions and interpret empirical data obtained from experimentation.

- ☐ A. design an experiment to determine the reactivity of various metals
- ☐ B. select and correctly use the appropriate equipment to perform a redox titration experiment
- ☐ C. use experimental data to construct a reduction potential table
- ☐ D. use numbers, variables and graphs to explain and model redox titrations

R2. Design experiments relating to electrochemical cells and interpret empirical data obtained from experimentation.

- ☐ A. design an experiment to test predictions regarding spontaneity, products and the standard cell potential for reactions occurring in electrochemical cells
- ☐ B. compare predictions with qualitative and quantitative observations of electrochemical cells
- ☐ C. identify the limitations of data collected on an electrochemical cell

APPENDIX B

PRE-TEST

CHEMISTRY 30 – **PRACTICE EXAM**
ELECTROCHEMISTRY

Name: _____

____ 1. When a substance undergoes oxidation, it always

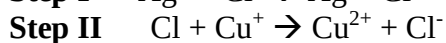
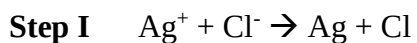
K1A

- a. loses electrons.
- b. decreases its oxidation number
- c. becomes positively charged
- d. attains a zero charge

Use the following information to answer the next 2 questions.

Photochromic glass can be made by trapping silver chloride crystals and copper(I) ions in a glass matrix as the glass solidifies. When this type of glass is exposed to sunlight, the silver ions are converted into silver atoms, which cause the glass to darken. The two steps that occur in this chemical reaction are represented below.

light



The reaction in the second step prevents the chlorine atoms from escaping from the glass.

____ 2. In step II, the Cu^+ ion acts as the**K1B**

- a. reducing agent and loses one electron
- b. oxidizing agent and gains one electron
- c. reducing agent and decreases in oxidation number
- d. oxidizing agent and increases in oxidation number

_____ 3. The half-reaction that causes the darkening of the glass is represented by the equation **K1E**

- a. $\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$
- b. $\text{Ag} \rightarrow \text{Ag}^+ + \text{e}^-$
- c. $\text{Cl}^- \rightarrow \text{Cl} + \text{e}^-$
- d. $\text{Cl} + \text{e}^- \rightarrow \text{Cl}^-$

_____ 4. An equation that represents a redox reaction is **S1A**

- a. $\text{NaOH(aq)} + \text{HCl(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)}$
- b. $\text{AgNO}_3\text{(aq)} + \text{KI(aq)} \rightarrow \text{AgI(s)} + \text{KNO}_3\text{(aq)}$
- c. $\text{Mg(OH)}_2\text{(s)} + \text{H}_2\text{SO}_4\text{(aq)} \rightarrow \text{MgSO}_4\text{(aq)} + 2 \text{H}_2\text{O(l)}$
- d. $\text{Cu(s)} + 4 \text{HNO}_3\text{(aq)} \rightarrow \text{Cu(NO}_3)_2\text{(aq)} + 2 \text{NO}_2\text{(g)} + 2 \text{H}_2\text{O(l)}$

_____ 5. The spontaneous reaction will occur when _____ *i* _____ is mixed with _____ *ii* _____. **K1C**

	<i>i</i>	<i>ii</i>
A.	$\text{Fe}^{2+}\text{(aq)}$	$\text{Pb}^{2+}\text{(aq)}$
B.	$\text{Cr}^{2+}\text{(aq)}$	$\text{Sn}^{2+}\text{(aq)}$
C.	$\text{Fe}^{2+}\text{(aq)}$	$\text{I}_2\text{(s)}$
D.	$\text{Na}^+\text{(aq)}$	Pb(s)

_____ 6. A solution of acidified potassium permanganate is stored in an iron container. The net ionic equation for a reaction that occurs is **S1C / S1D**

- a. $\text{MnO}_4^-\text{(aq)} + 8 \text{H}^+\text{(aq)} + 5 \text{K(s)} \rightarrow \text{Mn}^{2+}\text{(aq)} + 4 \text{H}_2\text{O(l)} + 5 \text{K}^+\text{(aq)}$
- b. $2 \text{MnO}_4^-\text{(aq)} + 16 \text{H}^+\text{(aq)} + 5 \text{Fe(s)} \rightarrow 2 \text{Mn}^{2+}\text{(aq)} + 8 \text{H}_2\text{O(l)} + 5 \text{Fe}^{2+}\text{(aq)}$
- c. $\text{MnO}_4^-\text{(aq)} + 8 \text{H}^+\text{(aq)} + \text{Fe}^{2+}\text{(aq)} \rightarrow \text{Mn}^{2+}\text{(aq)} + 4 \text{H}_2\text{O(l)} + \text{Fe}^{3+}\text{(aq)}$
- d. $\text{MnO}_4^-\text{(aq)} + 8 \text{H}^+\text{(aq)} + \text{Fe(s)} \rightarrow \text{Mn}^{2+}\text{(aq)} + 4 \text{H}_2\text{O(l)} + \text{Fe}^{2+}\text{(aq)}$

_____ 7. The oxidation numbers for the metals in the oxides of $\text{TiO}_2\text{(s)}$, $\text{MoO}_3\text{(s)}$, $\text{W}_4\text{O}_{12}\text{(s)}$, and $\text{W}_2\text{O}_5\text{(s)}$ are, respectively, **S1E**

- a. 4, 6, 24, and 10
- b. 2, 3, 3, and $\frac{5}{2}$
- c. 4, 6, 6, and 5
- d. 2, 3, 24, and $\frac{5}{2}$

____ 8. The titration required 55.0 mL of 0.100 mol/L $\text{KMnO}_4(\text{aq})$ to react completely with the $\text{Fe}^{2+}(\text{aq})$. The mass of iron in the ore sample was **S1G**

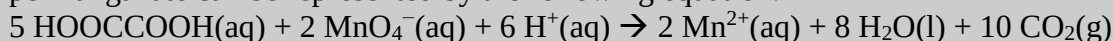
- a. 0.123 g
- b. 0.307 g
- c. 0.768 g
- d. 1.54 g

____ 9. It is estimated that up to 25% of the iron produced annually in North America is used to replace iron objects that have been damaged by rust. The corroded iron is often expensive or difficult to replace and is often disposed of in landfills. Corrosion is a concern from both **R1A**

- a. a political and a scientific perspective
- b. an ecological and an ethical perspective
- c. a technological and a scientific perspective
- d. an economic and an ecological perspective

Use the following information to answer the next 3 questions.

Poisonous oxalic acid is found in non-toxic concentrations in vegetables such as spinach and rhubarb. Manufacturers of spinach juice are required to analyze the concentrations of oxalic acid to avoid problems that could arise from unexpectedly high concentrations of oxalic acid. The reaction of oxalic acid with acidified potassium permanganate can be represented by the following equation.



____ 10. If 15.0 mL of oxalic acid solution is completely reacted with 20.0 mL of 0.0015 mol/L acidified permanganate solution, then the oxalic acid concentration will be **S1G**

- a. 8.0×10^{-4} mol/L
- b. 2.4×10^{-3} mol/L
- c. 5.0×10^{-3} mol/L
- d. 6.0×10^{-3} mol/L

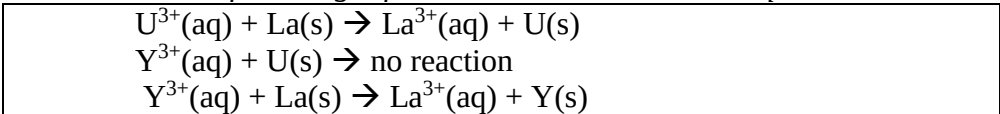
____ 11. A technician reacting oxalic acid with acidified potassium permanganate is **not** likely to observe **R1B**

- a. an increase in electrical conductivity
- b. a visible colour change
- c. a slight increase in pH
- d. the formation of a gas

____ 12. Acidic permanganate solutions and acidic dichromate solutions are often used in redox titrations because they are strong **S1F**

- a. reducing agents that change colour when they are reduced.
- b. reducing agents that change colour when they are oxidized.
- c. oxidizing agents that change colour when they are reduced.
- d. oxidizing agents that change colour when they are oxidized.

Use the following information to answer the next question.



____ 13. The oxidizing agents above, listed from strongest to weakest, are **R1C**

- a. $\text{U}^{3+}(\text{aq})$, $\text{La}^{3+}(\text{aq})$, $\text{Y}^{3+}(\text{aq})$
- b. $\text{U}^{3+}(\text{aq})$, $\text{Y}^{3+}(\text{aq})$, $\text{La}^{3+}(\text{aq})$
- c. $\text{Y}^{3+}(\text{aq})$, $\text{U}^{3+}(\text{aq})$, $\text{La}^{3+}(\text{aq})$
- d. $\text{U}(\text{s})$, $\text{Y}(\text{s})$, $\text{La}(\text{s})$

____ 14. Which of the following is true in a functioning electrochemical cell, **K2A**

- a. anions migrate inside the cell from the anode to the cathode.
- b. cations migrate inside the cell from the cathode to the anode.
- c. electrons move in the external circuit from the anode to the cathode, where reduction occurs.
- d. electrons move in the external circuit from the cathode to the anode, where reduction occurs.

____ 15. One way in which voltaic cells differ from electrolytic cells is that **K2B**

- a. anions migrate to the anode in one but to the cathode in the other.
- b. oxidation occurs at the cathode in one but at the anode in the other.
- c. voltaic cells have an external circuit but electrolytic cells do not.
- d. the cell potential for one is positive but negative for the other.

Use the following information to answer the next 2 questions.

Galvanizing, a process used to prevent corrosion, involves coating iron metal with a thin layer of zinc metal.

_____ 16. Iron nails can be galvanized using an electrolytic process. The nails to be galvanized would be attached to the **K2C**

- a. Anode
- b. electrode at which anions react
- c. electrode at which oxidation occurs
- d. electrode at which reduction occurs

_____ 17. A galvanized nail was placed in a copper(II) sulfate solution. After a day, the blue colour of the solution disappeared and copper metal was produced. The procedure was repeated with objects made of other metals. Similar results would **not** be predicted for **S2A**

- a. an uncoated iron nail
- b. a chromium-plated spoon
- c. a nickel-plated coin
- d. a gold-plated bracelet

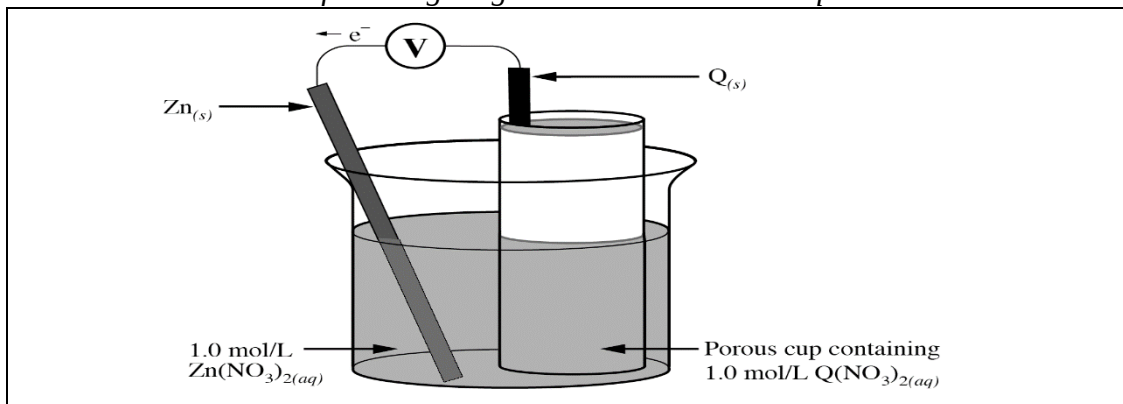
_____ 18. If the reference half-cell was changed to the standard nickel half-cell, the reduction potential of a standard bromine half-cell would be **K2E**

- a. +0.26 V
- b. +0.81 V
- c. +1.07 V
- d. +1.33 V

_____ 19. An electrolytic cell contains 2.00 mol/L $\text{NiCl}_2(\text{aq})$ and operates at 0.500 A. In order to plate 5.87 g of $\text{Ni}(\text{s})$, the cell will have to operate for **S2C**

- a. $1.93 \times 10^4 \text{ s}$
- b. $3.86 \times 10^4 \text{ s}$
- c. $7.72 \times 10^4 \text{ s}$
- d. $1.54 \times 10^5 \text{ s}$

Use the following diagram to answer the next question.



____ 20. Given that the reading on the voltmeter for this cell is +1.74 V, which of the following statements is correct? **K2E/R2B**

- The reduction potential of $Q^{2+}(aq)$ is +2.50 V.
- $Zn(s)$ is a weaker reducing agent than $Q(s)$.
- $Q^{2+}(aq)$ would react spontaneously with $Cu(s)$.
- $Q^{2+}(aq)$ is a stronger oxidizing agent than $Zn^{2+}(aq)$.

***** Numeric response questions are on the back of this page!

Numeric Response

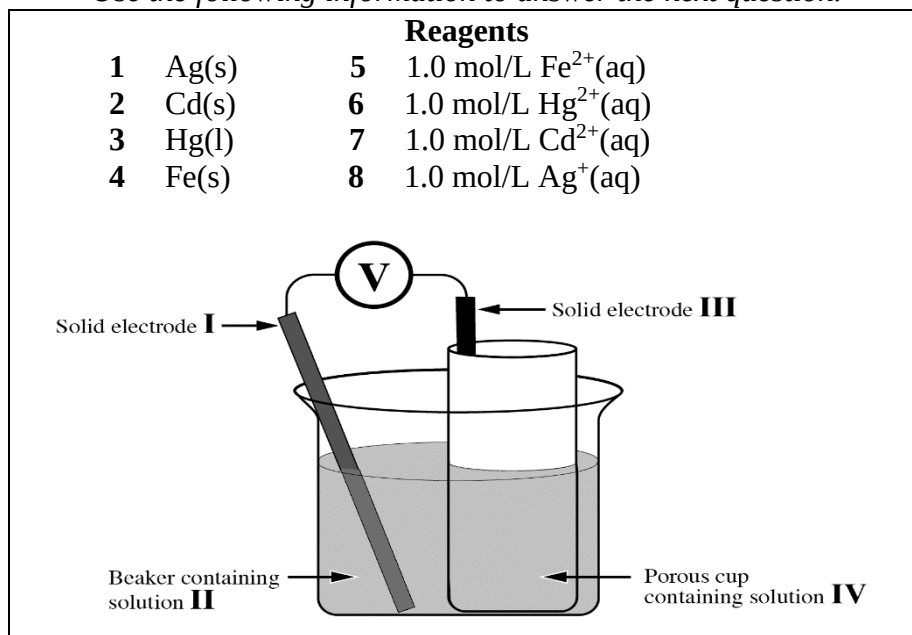
NR1. Using the Table of Standard Electrode Potentials, the numbered oxidizing agents listed from strongest to weakest are __, __, __, __. **S1B**

- 1 $Sn^{2+}(aq)$
- 2 $Cu^{2+}(aq)$
- 3 $Zn^{2+}(aq)$
- 4 $Pb^{2+}(aq)$

(Record your four digit answer in the numerical response section.)

NR2.

Use the following information to answer the next question.



What reagents are required in order for the cell to produce a voltage of 1.25 V? **S2A**

Electrode I _____ (Record in **first** column)

Solution II _____ (Record in **second** column)

Electrode III _____ (Record in **third** column)

Solution IV _____ (Record in **fourth** column)

(Record your four digit answer in the numeric response section.)

APPENDIX C

UNIT TEST

Electrochemical Changes Unit Exam**March 2017**

You **MAY** write on this exam, however, only responses recorded on the answer sheet will be scored.

Multiple Choice

Identify the choice that best completes the statement or answers the question.

Record all answers on the provided answer sheet.

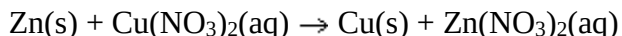
1. In $\text{Fe}_2(\text{SO}_4)_3$, the oxidation numbers of Fe, S, and O, respectively, are:
 - A. +2, +3, -4
 - B. +3, +6, -2
 - C. +2, +4, -8
 - D. +2, +4, -2

2. Which of the following statements about the reaction equation below is correct?
$$2 \text{MnO}_4^-(\text{aq}) + 5 \text{C}_2\text{O}_4^{2-}(\text{aq}) + 16 \text{H}^+(\text{aq}) \rightarrow 2 \text{Mn}^{2+}(\text{aq}) + 10 \text{CO}_2(\text{g}) + 8 \text{H}_2\text{O}(\text{l})$$
 - A. Hydrogen is oxidized and $\text{C}_2\text{O}_4^{2-}$ is the oxidizing agent.
 - B. Hydrogen is oxidized and MnO_4^- is the oxidizing agent.
 - C. Carbon is oxidized and H^+ is the oxidizing agent.
 - D. Carbon is oxidized and MnO_4^- is the oxidizing agent.

3. Which of the following equations does **not** represent an oxidation–reduction reaction?
 - A. $\text{Mg}(\text{s}) + 2 \text{HCl}(\text{aq}) \rightarrow \text{MgCl}_2(\text{aq}) + \text{H}_2(\text{g})$
 - B. $\text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g})$
 - C. $\text{SO}_3(\text{g}) + \text{CaO}(\text{s}) \rightarrow \text{CaSO}_4(\text{s})$
 - D. $2 \text{Na}(\text{s}) + 2 \text{H}_2\text{O}(\text{l}) \rightarrow 2 \text{NaOH}(\text{aq}) + \text{H}_2(\text{g})$

Use the following information to answer the next question.

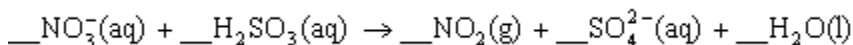
When zinc metal is placed into copper(II) nitrate solution, a solid precipitate forms according to the following reaction equation:



4. The observations a student would make from this redox reaction are:
the zinc _____ *i* _____ in mass and the copper (II) nitrate solution becomes
_____ *ii* _____ blue

	i	ii
A	increases	more
B	increases	less
C	decreases	more
D	decreases	less

5. Consider the following unbalanced redox reaction:



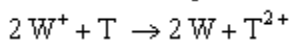
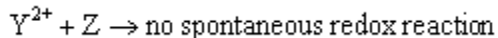
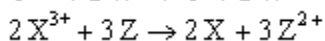
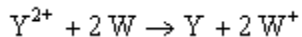
The balanced reduction half-reaction is:

- A. $\text{NO}_3^-(\text{aq}) + 2\text{H}^+(\text{aq}) + \text{e}^- \rightarrow \text{NO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
 B. $\text{H}_2\text{SO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) + 2\text{e}^-$
 C. $\text{NO}_3^-(\text{aq}) + \text{e}^- \rightarrow \text{NO}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g})$
 D. $\text{H}_2\text{SO}_3(\text{aq}) + 2\text{e}^- \rightarrow \text{SO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l})$

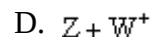
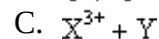
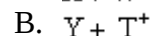
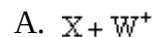
6. Which of the following is a spontaneous redox reaction?

- A. $\text{Fe}^{2+}(\text{aq}) + \text{Pb(s)} \rightarrow \text{Pb}^{2+}(\text{aq}) + \text{Fe(s)}$
 B. $2\text{NO}_3^-(\text{aq}) + 4\text{H}^+(\text{aq}) + \text{Sn}^{2+}(\text{aq}) \rightarrow \text{Sn}^{4+}(\text{aq}) + \text{N}_2\text{O}_4(\text{g}) + \text{H}_2\text{O}(\text{l})$
 C. $\text{Cr}^{2+}(\text{aq}) + \text{H}_2\text{SO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) + \text{Cr(s)}$
 D. $2\text{Fe}^{2+}(\text{aq}) + \text{Ni}^{2+}(\text{aq}) \rightarrow 2\text{Fe}^{3+}(\text{aq}) + \text{Ni(s)}$

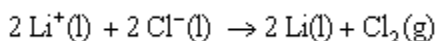
7. Consider the following information:



Which reaction is spontaneous?



8. Lithium, a strong oxidizing agent, is often used as the anode in batteries. It can be produced from molten lithium chloride according to the following equation:



If a current of 2.5 A is passed through a solution of molten lithium chloride for 8.5 h, *i* g of lithium will be produced at the *ii* .

	<i>i</i>	<i>ii</i>
A	5.5	anode
B	5.5	cathode
C	11	anode
D	11	cathode

9. Which of the following statements are true for all voltaic cells?

I. electrons flow from the anode to the cathode

II. reduction occurs at the anode

III. oxidation occurs at the cathode

IV. oxidation occurs at the anode

V. reduction occurs at the cathode

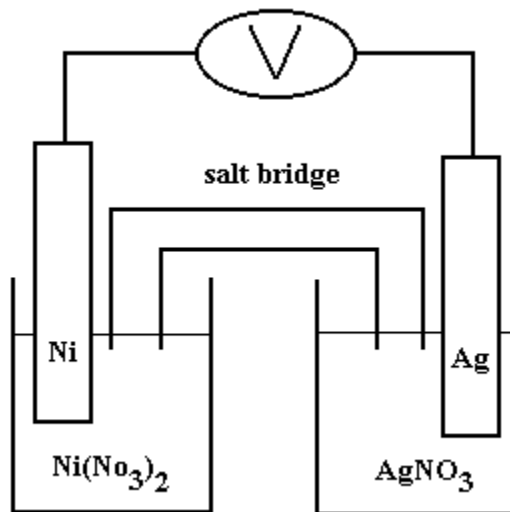
A. I, IV, and V

B. I, II, and III

C. II and III

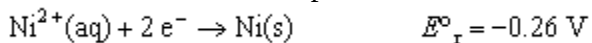
D. IV and V

Use the following information to answer the next question.



10. The concentrations of both solutions in the cell above are 1.0 mol/L.

The standard reduction potentials are:

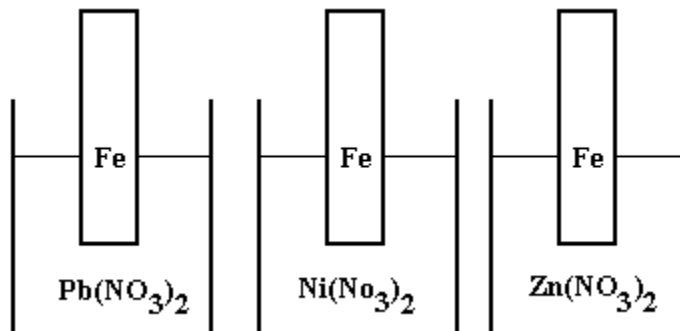


Which of the following statements are true?

- I. Oxidation occurs at the Ag electrode.
- II. The Ag electrode is the negative terminal of the cell.
- III. Electrons flow from the Ni electrode to the Ag electrode through the external circuit.
- IV. The Ni electrode is the anode.

- A. I and II
- B. I and III
- C. II and III
- D. III and IV

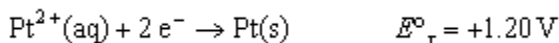
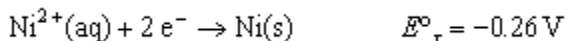
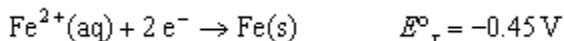
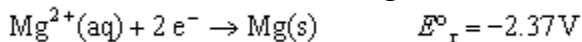
11. Which beakers, pictured below, will show evidence of a spontaneous reaction?



- I. $\text{Fe}(s) + \text{Pb}^{2+}(\text{aq}) \rightarrow \text{Fe}^{2+}(\text{aq}) + \text{Pb}(s)$
 II. $\text{Fe}(s) + \text{Ni}^{2+}(\text{aq}) \rightarrow \text{Fe}^{2+}(\text{aq}) + \text{Ni}(s)$
 III. $\text{Fe}(s) + \text{Zn}^{2+}(\text{aq}) \rightarrow \text{Fe}^{2+}(\text{aq}) + \text{Zn}(s)$

- A. I only
 B. I and II
 C. I and III
 D. II and III

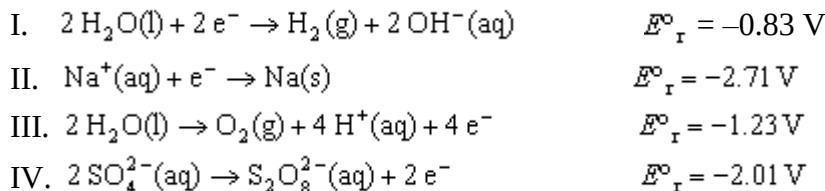
12. Consider the following half-cell reactions:



Which of the following half-cells, when combined with a standard hydrogen reference half-cell, will produce an electric cell with the greatest voltage?

- A. magnesium–magnesium ions
 B. iron–iron ions
 C. nickel–nickel ions
 D. platinum–platinum ions

13. Inert electrodes are used in the electrolysis of a sodium sulfate solution, $\text{Na}_2\text{SO}_4(\text{aq})$. Consider the following possible half-cell reactions:



What is the expected cathode reaction?

- A. I
- B. II
- C. III
- D. IV

14. Which of the following statements about electrolytic cells is **false**?

- A. An electrolytic cell cannot operate without energy provided by an external source.
- B. The anode of an electrolytic cell is the negative electrode.
- C. The anode of an electrolytic cell is where oxidation occurs.
- D. The cathode of the electrolytic cell is where reduction occurs.

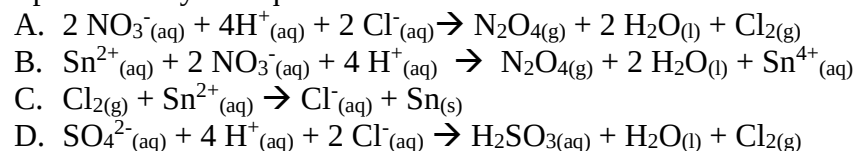
15. Calculate the current applied to an electrolytic cell to transfer 0.50 mol of electrons while the cell is operating for 30.0 min.

- A. 27 A
- B. 1.6 kA
- C. 0.45 A
- D. 10 A

16. In a disproportionation redox reaction,

- A. atoms of the same substance are only oxidized.
- B. atoms of the same substance are only reduced.
- C. atoms of the same substance are oxidized as well as reduced.
- D. atoms of the same substance are neither oxidized nor reduced.

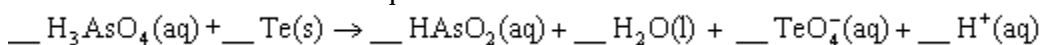
17. A high school laboratory's waste container is used to dispose of aqueous solutions of sodium nitrate, potassium sulfate, hydrochloric acid, and tin(II) chloride. The most likely net redox reaction predicted to occur inside the waste container is represented by the equation:



18. The minimum voltage required to electrolyze a 1.00 mol/L solution of nickel (II) sulfate at standard conditions is:
- 0.17 V
 - 1.49 V
 - 0.97 V
 - 0.43 V
19. When molten aluminum bromide is electrolyzed, the following entities are produced:
- | | |
|---|---|
| A. at the cathode: $\text{H}_{2(g)}$ and $\text{OH}^{-}_{(aq)}$ | at the anode: $\text{O}_{2(g)}$ and $\text{H}^{+}_{(aq)}$ |
| B. at the cathode: $\text{Al}_{(l)}$ | at the anode: $\text{Br}_{2(g)}$ |
| C. at the cathode: $\text{Al}^{3+}_{(l)}$ | at the anode: $\text{Br}^{-}_{(l)}$ |
| D. at the cathode: $\text{Al}_{(s)}$ | at the anode: $\text{O}_{2(g)}$ and $\text{H}^{+}_{(aq)}$ |

Numeric Response

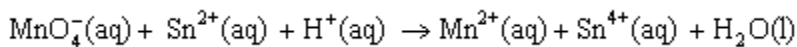
1. Determine the coefficients for the elements and compounds in the given **unbalanced** redox reaction equation:



_____ Te(s) (record answer in first blank)
 _____ HAsO₂(aq) (record answer in second blank)
 _____ H₂O(l) (record answer in third blank)
 _____ H⁺(aq) (record answer in fourth blank)

2. Use the following information to answer the next question.

In a typical redox titration, a solution containing the permanganate ion can be added to tin(II) ion solution according to the following **unbalanced** equation:



If 13.5 mL of 0.098 mol/L $\text{KMnO}_4(\text{aq})$ is added to 10.0 mL of $\text{Sn}^{2+}(\text{aq})$, then the concentration of $\text{Sn}^{2+}(\text{aq})$ is _____ mol/L.

3. The following observations were made when metals Pt, V, Pd, and Mo were placed into metallic ion solutions of each element.

	Pt ²⁺	V ²⁺	Pd ²⁺	Mo ³⁺
Pt(s)	---	√	√	√
V(s)	X	---	X	X
Pd(s)	X	√	---	√
Mo(s)	X	√	X	---

Given the following list of oxidizing and reducing agents:

1. Pt(s)	5. Pt ²⁺
2. V(s)	6. V ²⁺
3. Pd(s)	7. Pd ²⁺
4. Mo(s)	8. Mo ³⁺

List the oxidizing agents from strongest to weakest.

APPENDIX D
STUDENT REFLECTION SHEET

Chemistry 30: Practice Unit-Test Student Reflection Sheet

Name: _____

Use the space below to record the knowledge, skills or reasoning outcomes that you need to work on to best be prepared for the upcoming outcomes assessment.

Instructions:

1. During the unit pre-test; make a note of which question number and its associated outcome you are having trouble with. You should also record any thoughts you have about the question and/or anything you find confusing.
2. While Mr. Madsen scores your practice test, use the outcome code you recorded to make a list of worksheets, assignments, textbooks pages etc. that you can use to review the outcome.

[illegible]

[illegible]

APPENDIX E
STUDENT ATTITUDE SURVEY

Student Attitude Survey

Think about your experiences in chemistry so far this semester. Read each question carefully and then select your response. Please be honest with your responses. All responses are anonymous.

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way. No identifying information is being recorded.

***Required**

I use feedback I receive in class to help me determine what I need to study. *

Always
Sometimes
Rarely
Never

I understand what the curriculum requires me to know in chemistry class. *

Always
Sometimes
Rarely
Never

Unit pre-tests help me to study for unit tests. *

Always
Sometimes
Rarely
Never

The unit pre-test reflection sheet was useful. *

Always
Sometimes
Rarely
Never

I used the unit pre-test reflection sheet to guide my studying for the unit test. *

Always
Sometimes
Rarely
Never

The unit pre-test reflection sheet helped me to target my studying to skills that I needed to improve. *

Always
Sometimes
Rarely
Never

The unit pre-test increased my confidence going in to the unit test. *

Always
Sometimes
Rarely
Never

Unit pre-tests make me aware of what I do and don't know in Chemistry 30. *

Always
Sometimes
Rarely
Never

I feel more comfortable about chemistry because I know more about the curriculum expectations. *

Always
Sometimes
Rarely
Never

Knowing which curriculum outcomes I am responsible for has made me more confident in chemistry. *

Always
Sometimes
Rarely
Never

I am aware of the things I do know and what I do not know in chemistry. *

Always
Sometimes
Rarely
Never

SUBMIT

APPENDIX F
STUDENT INTERVIEW QUESTIONS

Student Interview Questions (Post-Unit Test) Madsen – Chemistry 30 (Periods 1 and 3)

Think about your experiences in chemistry so far this semester. Read each question carefully. Let Mr. Madsen know when you are ready to talk about your responses.

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way. No identifying information is being collected.

Student Interview Questions

1. Do you like the unit pre-tests?
2. How do you feel about the unit pre-tests?
3. Do you find the unit-pre-tests helpful?
4. Do the curriculum indicators help you to focus your studying?
5. Do you think you have a better understanding of what material you need to focus on in chemistry?
6. Is there anything about the unit pre-tests or student reflections you do not like?
7. Is there anything about the pre-tests and/or student reflections that you would like to see changed?

APPENDIX G
INSTITUTIONAL REVIEW BOARD EXEMPTION



INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

960 Technology Blvd. Room 127
 c/o Microbiology & Immunology
 Montana State University
 Bozeman, MT 59718
 Telephone: 406-994-6783
 FAX: 406-994-4303
 E-mail: cherylj@montana.edu

Chair: Mark Quinn
 406-994-4707
 mquinn@montana.edu
Administrator:
 Cheryl Johnson
 406-994-4706
 cherylj@montana.edu

MEMORANDUM

TO: Joseph Madsen and Marcie Reuer
FROM: Mark Quinn *Mark Quinn cy*
DATE: November 28, 2016
SUBJECT: "Using Metacognitive Strategies to Improve Student Performance and Confidence in High School Chemistry" [JM112816-EX]

The above research, described in your submission of November 28, 2016, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

- ☒ (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
- ☒ (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.
- ☐ (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
- ☐ (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.
- ☐ (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.
- ☐ (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.