LABORATORY SKILLS PERFORMANCE ASSESSMENTS IN CHEMISTRY

by

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DEDICATION

This paper is dedicated to all of my teachers and students. Teaching and learning have filled my life, thank you to all those who have played a part.

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I would like to acknowledge my committee members, Dr. John Graves, Dr. Candace Goodman, and Diana Paterson whose council has been greatly appreciated. In addition, I would like to thank Kristian Basaraba for his inspiration. Most importantly, I would like to thank Lisa, Elena and Marie for their support and encouragement.

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ABSTRACT

The use of performance assessments in the chemistry laboratory present unique opportunities for formative assessment. When used in conjunction with student self-assessment checklists performance assessments can also promote metacognitive activity. In this study students were given explicit instruction in basic lab skills and then completed individual performance assessments where they demonstrated their ability. The lab skills assessed were measuring mass using an electronic balance, measuring volume using a graduated cylinder, lighting a Bunsen burner, measuring volume using a pipet, and completing one trial of a titration. Pre- and post-treatment tests, surveys, self-assessments, skill assessment rubrics, formative quizzes, a summative unit exam, and interviews were used as data collection instruments. Data were processed using both quantitative and qualitative methods. The results indicated a positive change in students' attitudes toward chemistry and the laboratory. Also, the results showed that students made gains in their ability to perform laboratory skills. Finally, students made progress academically as a result of the treatment.

INTRODUCTION AND BACKGROUND

My goal for my capstone project, that was based on the action research model, was to focus on an aspect of my teaching practice that would potentially benefit all of the students that I teach and that would drive my pedagogical approach in the classroom forward. I decided to conduct performance assessments of student lab skills in an effort to help my students develop those skills and to thereby increase their confidence and competence in the lab. In addition, I wanted to promote a more reflective attitude and metacognitive thought processes in my students with the ultimate goal of increasing their conceptual level of understanding and academic achievement.

The students involved in this study attended Salisbury Composite High School in Sherwood Park, Alberta, Canada. Sherwood Park is a suburban community that is located to the east of the provincial capital of Edmonton. The community lies on Treaty 6 territory which is a traditional gathering place for diverse Indigenous peoples including the Cree, Blackfoot, Métis, Nakota Sioux, Iroquois, Dene, Ojibway, Saulteaux, Anishinaabe, Inuit, and many others whose histories, languages, and cultures continue to influence the region. According to Statistics Canada, the results of the 2011 census indicated that Sherwood Park had a population of 135,155 people. The population was predominantly Caucasian with only 13.7% being a visible minority. The median family income was $106,142, and the mean family income was $122,979 with 55.1% of adults having some level of post-secondary education.

Salisbury Composite High School is one of two public high schools in the community and belongs to the Elk Island Public Schools Division of the province. It teaches the Alberta Program of Studies to grades 10 through 12 and also offers the International Baccalaureate program. The school had an enrollment of 1090 students, with 375 in grade 10, 350 in grade 11, and 365 in grade 12 (C. Allen, personal communication, January 26, 2018). The composition of the school reflects that of the community, so it's predominantly Caucasian. Ninety-seven percent of students at Salisbury complete their graduation requirements. The independent Fraser Institute academically ranked Salisbury 150th out of 246 Alberta High School over the last five years.

I selected my Chemistry 20 class for my research treatment because it was a course that I was very familiar with. I have taught it for over a decade. Chemistry 20 was a grade 11 course that followed the Alberta Program of Studies. It consisted3 of four units of study: the diversity of matter and chemical bonding, gases, matter as solutions, and quantitative relationships in chemical changes. My lesson and unit plans were well established and the lab skills that I wanted to focus on with my performance assessments were all reflected in the lab experiments and activities that I habitually used as part of my delivery of this course. In addition, I thought that by choosing to deliver the treatment to a grade 11 class the potential benefits of the treatment would carry forward to their grade 12 year. If the performance assessments of the lab skills that I focused on increased students' confidence and comfort level in the lab then that would clearly serve them well in the subsequent course. Finally, there was enough space in the Chemistry 20 curriculum for me to find the class time necessary to conduct the performance assessments. Performing multiple individual performance assessments with a group of over 30 students was a time-consuming process; however, I did not have to sacrifice other activities or have to push through the content of the course in order to create the time that I anticipated needing for my action research.

My past practice has been to attempt to include as many laboratory activities and experiments as possible into my delivery of the curriculum that I am responsible for. My goal for my students' lab work had been to reinforce the concepts that I was teaching by providing students with the opportunity to experience relevant chemical phenomena first-hand. I wanted my students to have the chance to see and touch the chemicals, glassware, and technology used in the lab. I have tried to use lab work to encourage learning and to contextualize the abstract and theoretical concepts that we were covering in the classroom. My experience had been that students do enjoy lab work and that it is a valuable way to support learning. In spite of all the many positives experiences with students in the lab, I have observed that many students do not seem comfortable there, and that some students rely on their partners to get their work done, or simply don't take the lab seriously. Often one student will be working hard trying to learn new skills or to develop their understanding, but their partner is not participating fully, and is not fully engaged. I have questioned the reason for this lack of engagement, and I think that it could potentially have to do with a lack of confidence working with the equipment, a general dislike of the lab, or even of chemistry more broadly.

A second issue that I have encountered in the past in regards to student lab work is that I have found that I have assumed students have certain basic lab skills when, in fact, many students don't have them. Further to this, students themselves sometimes think that they have the correct skills, when they actually do not. This false confidence in their lab skills demonstrates a gap somewhere in their self-assessment of their lab skills, and their metacognitive reflection on their abilities.

My experience with my classes this year lead to the creation of my focus statement: What are the effects of laboratory skills performance assessments on a grade 11 chemistry class? Besides the main focus question, sub-questions were created as follows:

1. What is the effect of lab skills performance assessments on student attitudes toward laboratory work?
2. What is the effect of lab skills performance assessments on student attitudes toward chemistry more broadly?
3. What is the effect of laboratory skills performance assessments on students' metacognitive level?
4. What is the effect of laboratory skills performance assessments on students' academic achievement?

CONCEPTUAL FRAMEWORK

The role of metacognition in student learning has been concluded to be important to a wide array of oral and written tasks (Flavell, 1979). This includes such diverse behaviors as oral communication of information, reading comprehension and language acquisition. More broadly, an increased level of metacognitive activity is important for developing a deeper understanding of ideas, and has a significant impact on problem-solving success. The ability of students to monitor their own learning and employ metacognitive strategies when they encounter new material are crucial components of scientific thinking and effective learning. Students who have developed metacognitive skills are more capable of refining, and adapting, their understanding in an appropriate and flexible way. Therefore, enhancing students' metacognitive level, and in turn their problem-solving skills, are important parts of chemistry education. Helping students to develop their awareness of their own ideas, and an awareness and control of their thinking, is a way to develop their level of metacognition. This is important because increasing students' consciousness of their developing understanding of novel concepts is key for effective learning (Rickey & Stacy, 2000).

Rather than operating under the belief that metacognitive thinking strategies will be picked up by students from their experiences in the classroom, these strategies need to be explicitly taught. Research has revealed that providing direct instruction in metacognitive thinking strategies resulted in a positive effect on students' academic performance. Additionally, where high achieving students frequently develop metacognitive strategies independently, lower achieving students are often less likely to do so. As a result, the explicit instruction of metacognitive strategies had a greater impact on the thinking of low achieving students. Instruction in metacognitive strategies is therefore both invaluable and essential because all students will benefit from it. The way that direct instruction in metacognitive strategies impacts low achieving students is complemented by the use of formative assessments (Ben-David & Zohar, 2009).

Formative assessment is an assessment that provides information to teachers and students about how well students are learning. This information is then used to modify instruction to better meet student learning needs and to thereby better prepare students for future evaluations (Angelo & Cross, 1993). The best types of formative assessments act as sources of information on student learning. The information can be used to guide corrective instruction and to prevent minor learning errors from becoming major ones. Indeed, formative assessments can be viewed as a fundamental and vital part of the instructional process and are integral in helping students learn (Guskey, 2003). Ultimately, effective teaching is fundamentally about student learning. Formative assessments are not about assigning grades, for accountability to outside stakeholders, and are not perfectly ordered. In short, they are not an end in themselves but should support student learning, and inform future pedagogical choices made by the teacher (Tanner & Allen, 2004).

Improving the way that teachers use formative assessment results in significant and substantial learning gains. Enhancing the use of formative assessment raises achievement overall, narrows the range of achievement, and helps low achieving students in particular. One key aspect to improving the practice of formative assessment is to create a culture of success in the classroom, rather than one focused on grades. It is therefore important that teacher feedback to individual students should be about the quality of their work, and include advice on what the student can do to improve, while avoiding making comparisons to other’s work. In addition, breaking the cycle of ineffective classroom dialogue to encourage all students to generate, and think about, their answers is a way to promote thoughtful reflection and a way to encourage all students to take part (Black & Wiliam, 1998).

It has been argued that promoting mastery learning and an intrinsic motivation for learning can help students to develop high self-efficacy and attribute their success to their effort level. Formative assessments that are frequent, specific and that include meaningful feedback are a powerful technique to support student motivation and achievement. Demonstrating to students how to improve the quality of their work, and allowing them to see their own progress, in a defined way, is a motivational force. By attributing success to effort, and raising expectations, students will feel empowered and thereby will be more likely to persevere when confronted with difficult concepts or challenging work. In addition, formative assessments should provide clear learning targets, encourage self-assessment, help students to set attainable goals for improvement and allow students to see their progress toward those goals. The end products of the effective use of formative assessments are increased student motivation and achievement (Cauley & McMillan, 2010).

Using assessment as an instructional strategy has a positive impact on student metacognition, motivation and achievement (Brookhart, Moss & Long, 2008). Clearly setting the learning outcomes for students is vital to this process. Students need to know where their destination is in order to be able to judge their progress toward reaching it. In addition, the educational value of providing regular descriptive feedback on what students are doing well, plus providing guidance about how to improve is essential to learning. Feedback of this type will allow students to develop greater self-efficacy and metacognitive skills by linking the actions taken by students and what they learned. The overall result will be to thereby enhance student motivation and achievement (Black, Harrison, Lee, Marshall, Wiliam, 2004).

In the science classroom, the use of the laboratory presents unique opportunities for formative assessment because of the way that it allows students to demonstrate their technical lab skills, as well as their problem-solving skills, when confronted with authentic problems. Skills tasks are a type of performance assessment where students are required to display their competence using lab equipment to perform tasks using apparatus and instruments. Skills tasks are a good way to begin to use this type of assessment because of its level of familiarity to students and teachers. Investigations are another form of assessment, which are often seen as more involved than skills tasks. Investigations are authentic lab activities that require students to follow the full scientific process. These assessments will have students analyze a problem, design and then conduct an experiment while gathering data. Finally, students will need to organize their results and then clearly communicate what they have found (Doran, Chan, Tamir & Lenhardt, 2002).

The importance of authenticity in the science classroom is significant because contextualizing activities to be based on real-world problems is a way to enhance learning (Alesandrini & Larson, 2002). Students in a decontextualized setting often do not see the relevance of what they are learning to their own lives. However, performance tasks, in addition to assessing student abilities, offer students authentic experiences through which understanding can be constructed and therefore work as instructional tools to enhance student learning (Ernst, Glennie & Songze, 2017).

Research has been conducted that addressed the performance-based approach of assessment in the chemistry classroom. A performance-based approach was found to more effectively engage students with the concepts taught and increased how students saw the relevance of chemistry in their own lives. In addition to using traditional assessment techniques students were also assessed using a variety of alternative and authentic methods. The nontraditional assessments, which included laboratory performance assessments, were found to measure higher-order thinking skills. The application of this redesigned approach led to increased enrollment in subsequent chemistry courses, rising achievement scores, and an increase in the number of students with a desire to major in chemistry in their post-secondary studies (Wygoda & Teague, 1995).

Further to this is the idea that performance assessments have real value from a constructivist perspective. Constructivism adheres to the idea that new understandings don't come out of nowhere and aren't stored in isolation. Rather, new concepts are grafted onto and assimilated into the preexisting ideas and conceptions held by the student (Black & Wiliam, 1998). From a constructivist perspective, meaning and understanding of new material is based off of, and integrated into the student's previous experience (Alesandrini & Larson, 2002). By engaging students in authentic laboratory performance assessments, opportunities are provided for them to construct meaning and to internalize new ideas and concepts. The lab can effectively support constructivist teaching approaches when it exposes students to meaningful investigations that are challenging and upon which they can construct scientific concepts (Hofstein & Lunetta, 2002). Performance tasks give students the chance to interact with science concepts and applications, and can assess higher-order thinking abilities and student procedural knowledge (Ernst, Glennie & Songze, 2017).

Student self-assessment checklists and performance assessments conducted by the teacher draw together metacognition and formative assessment. There are clear metacognitive dimensions to self-assessment that makes using them a valuable form of formative assessment. Using self-assessments promotes students' reflection on their own thought processes, and their own learning, in a way that is beneficial to their learning and helps them to develop an overview of their learning progress, to manage it, and to control it themselves (Black, Harrison, Lee, Marshall & Wiliam, 2004). Self-assessment is more than having students check over their own answers from a key. Self-assessment tools encourage students to monitor and evaluate their thought processes and to identify strategies to improve understanding (Cauley & McMillan, 2010).

The impact of using laboratory performance assessments in conjunction with student self-assessments as a metacognitive strategy will influence student attitudes about science and their learning. The promotion of hope, effort and optimism in students about their learning and providing clear expectations for, and examples of, what success looks like are key aspects of assessment for learning (Stiggins, 2005). Drawing the connection between effort and achievement has a positive effect on student motivation and engagement, and will positively influence students' feelings about their competence, and their ideas about how to advance their learning (Brookhart, Moss & Long, 2008). Students make decisions about their learning based on data and if they react to the data about their progress in a positive way, because of the support they receive in the classroom, then any gap that exists between their current level of understanding and their own educational goals can be closed (Stiggins, 2005). Moreover, authentic experiences in the laboratory can positively influence student attitudes and interest in science, while promoting collaboration amongst students. Laboratory work enhances attitudes, stimulates interest and motivates students to learn science (Hofstein & Lunetta, 2002).

METHODOLOGY

The action research described in this paper took place over a period of approximately seven weeks during which students were studying a unit on stoichiometry. Specifically, this research was conducted during my delivery of the Alberta Chemistry 20 unit called Quantitative Relationships in Chemical Changes. There were two general outcomes in this unit. The first one was that students would explain how balanced chemical equations indicate the quantitative relationships between reactants and products. The second outcome was that students use stoichiometry in quantitative analysis (Alberta, 2007). The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained (Appendix A).

The treatment that I implemented was to incorporate performance assessments for five lab skills into my normal instruction. The five skills were using an electronic balance to measure mass, using a graduated cylinder to measure a volume, lighting a Bunsen Burner, pipetting a series of prescribed volumes, and performing one trial of an acid-base titration. After delivering a brief lesson on each of the skills I had all students individually perform the prescribed technique while I observed them and completed a marking rubric. My research question was to test what effect these lab skills performance assessments would have on student attitudes toward the chemistry laboratory, and toward chemistry more broadly. In addition, I wanted to see if using these types of performance assessments would impact student levels of metacognition. Finally, I wanted to see if my use of these skill assessments would affect academic achievement.

I was fortunate this semester to be teaching two course sections of Chemistry 20, so to gauge the effectiveness of this treatment I used one of my classes as a treatment group, and the second class as a non-treatment group. The treatment group was a grade 11 chemistry class with 27 students, 17 females and 10 males. The non-treatment group was also a grade 11 chemistry class, which consisted of 31 students, 22 females and 9 males. In order to verify whether or not the two groups were comparable, a pre-treatment Chemistry Skills Review Exam was given to both groups prior to beginning the unit (Appendix B). This review exam tested students' abilities to work with significant digits and scientific notation, as well as writing chemical formulas, writing and balancing chemical equations, determining molar mass, and calculating moles. The results of this exam were analyzed to determine the mean, standard deviation and range for each group. The two groups were compared by using an unpaired two-tailed t-test. Following the treatment, both groups also completed an analogous exam, called Chemistry Skills Review Exam II (Appendix C). This second review exam was analyzed in the same way as the first exam, for mean, standard deviation and range for each group, with the two groups being compared using an unpaired two-tailed t-test. In addition, the results of these review exams were analyzed for each group to determine normalized gains, and a paired two-tailed t-test was performed to compare the results of the pre-test and post-test for each group.

Prior to beginning the treatment, both classes of students also completed the Science Attitudes Survey (Appendix D). For both the treatment group and the non-treatment group not all of the students returned their IRB approval forms signed by their parents. As a result, the Science Attitudes Survey was only administered to 20 students in the treatment and non-treatment groups. The Science Attitudes Survey was a 17 question Likert survey that asked students to respond with their level of agreement to statements about the chemistry laboratory, chemistry in general, and their metacognitive activities. Students could choose a 5 for strongly agree, 4 for agree, 3 for neutral, 2 for disagree, or a 1 for strongly disagree. This survey was also completed post-treatment by both groups. The results of this survey were analyzed in a couple of ways. First, each question was analyzed for changes within each group by using a Wilcoxon Signed Rank Test. Second, the student responses for each question pre-treatment and post-treatment was analyzed between the two groups by using the Wilcoxon Rank Sum test. The idea here was that this survey would be a way to gather data to measure the changes in student attitudes over the course of their unit of study on stoichiometry

A third instrument was also used for both groups before the treatment began. Both groups completed the Chemistry Lab Skills Self-Assessment (Appendix E). This instrument was a five-question self-assessment that asked students to rate their level of proficiency on the five lab skills that the treatment would address: using the electronic balance and the graduated cylinder, lighting a Bunsen Burner, pipetting, and carrying out a titration. The assessment was not a Likert survey; rather, it asked students to assess their skill level as needs improvement, proficient or exemplary. Following the treatment both groups completed this assessment again. The means of the student responses for each of the skills were analyzed as a way to compare them pre-treatment and post-treatment. Also, normalized gains for each skill were calculated, as was the average normalized gain. Finally, the frequency of students' self-reported proficiency level for each lab skill was analyzed.

Throughout my delivery of the unit students in the treatment group individually completed five performance assessments. I had stations set up in my classroom or in one of the chemistry labs at my school and watched each student perform the lab skill in question while I completed an assessment rubric (Appendices F-J). In contrast, the non-treatment group did not receive additional instruction in these lab techniques and did not complete any performance assessments. Both groups completed five lab exercises in common and were exposed to the same experiments and procedures during these labs. In short, I handled the non-treatment group using my established pedagogical delivery, and added in the performance assessments for the treatment group.

As a way to gather data on academic achievement both the treatment group and the non-treatment group completed the same formative quizzes and the same summative unit exam. There were three formative quizzes that were completed during the unit of study. The first was the Gravimetric Stoichiometry Quiz (Appendix K). This quiz was four questions in length and asked students to solve four different styles of gravimetric stoichiometry problems: mole to mole, mole to mass, mass to mole, and mass to mass. The second quiz was the Solution Stoichiometry Quiz (Appendix L). This quiz was five questions in length and asked students to perform calculations to determine mass, volume or concentration by applying their knowledge of stoichiometry. The third quiz was the Gas Stoichiometry Quiz (Appendix M). This quiz had four questions and asked students to use stoichiometry to determine mass, volume, pressure and concentration. All three quizzes were analyzed to determine the mean, standard deviation and range for each group. In addition, the results of each quiz were compared between the treatment and non-treatment groups by using an unpaired two-tailed t-test. At the end of the unit of study both groups also wrote the Stoichiometry Unit Exam (Appendix N). This exam was composed of 15 multiple choice questions and 5 short answer questions. This was a summative exam that assessed all of the topics that were covered in the unit. Like with the formative quizzes the results of the unit exam were analyzed to determine the mean, standard deviation and range for each group, and the two groups were compared using an unpaired two-tailed t-test.

Following the completion of the unit of study, student volunteers were interviewed and asked the Student Interview Questions (Appendix O). These questions were designed to attempt to gain deeper insight into student's thoughts about the value of the laboratory skills performance assessments, and the impact these performance assessments had on them.

Table 1 summarizes all of the data sources that were used to evaluate my research questions. A range of data sources were administered pre-treatment and post-treatment to measure changes in student attitudes, levels of metacognition, and academic achievement. These instruments represent a good mix of qualitative and quantitative data by incorporating student surveys, self-assessments, student interviews, as well as written formative and summative assessments.

Table 1
Data Triangulation Matrix

Focus Question	Data Source 1	Data Source 2	Data Source 3
What effect do laboratory skills performance assessments have on student attitudes toward the laboratory?	Science Attitudes Survey	Chemistry Lab Skills Self-Assessment	Student Interview Questions
What effect do laboratory skills performance assessments have on student attitudes toward chemistry?	Science Attitudes Survey	Student Interview Questions	
What effect do laboratory skills performance assessments have on student metacognition?	Science Attitudes Survey	Chemistry Lab Skills Self-Assessment	Student Interview Questions
What effect do laboratory skills performance assessments have on student academic achievement?	Chemistry Skills Review Exams	Formative Quizzes and the Summative Unit Exam	Student Interview Questions

DATA AND ANALYSIS

The results of the pre-treatment Chemistry Skills Review Exam on the treatment group were a mean of 63.93%, with a standard deviation of 18.37 and a range of 69%

(N=27). The non-treatment group's results were a mean of 67.16%, with a standard deviation of 20.35 and a range of 67% (N=31). A two-tailed unpaired t-test was conducted which resulted in a p-value of 0.53. This is not considered a statistically different result; therefore, the two groups are comparable.

The results of the post-treatment Chemistry Skills Review Exam on the treatment group was a mean of 83.11%, with a standard deviation of 9.24 and a range of 35% (N=27). The average normalized gain for the treatment group was 50%. Eighty-five percent of students had positive normalized gains, 4% had zero normalized gains, 4% of students had negative normalized gains, and 7% had an undefined normalized gain and so are not included in Figure 1. About the Chemistry Skills Review Exam one student said, "Working on those kinds of questions made me more confident about the rest of the unit."

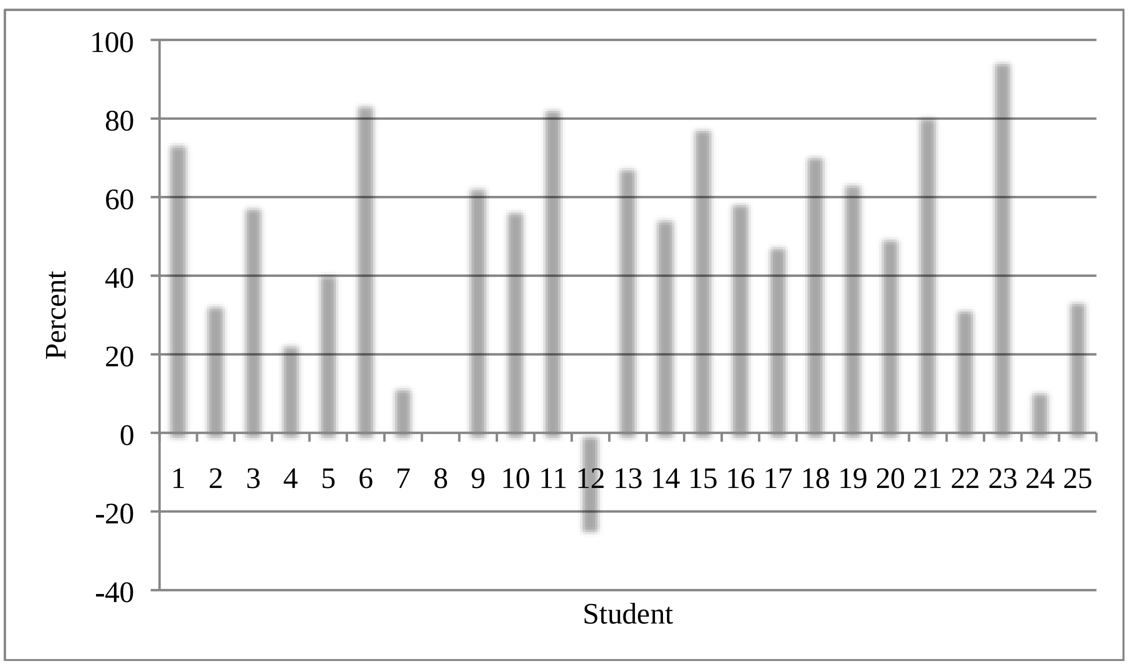

Figure 1. Treatment group Chemistry Skills Review Exam normalized gains, (N=25).

The non-treatment group's results on the post-treatment Chemistry Skills Review Exam were a mean of 77.65%, with a standard deviation of 15.42 and a range of 56% (*N*=30). To compare the two groups a two-tailed unpaired t-test was conducted which resulted in a p-value of 0.11. This result is not considered statistically different from the treatment group. The average normalized gain for the non-treatment group was 28% (*N*=31). Seventy-eight percent of students had positive normalized gains, 3% had zero normalized gains, and 19% had negative normalized gains (Figure 2). One student said, "It made me realize what was important."

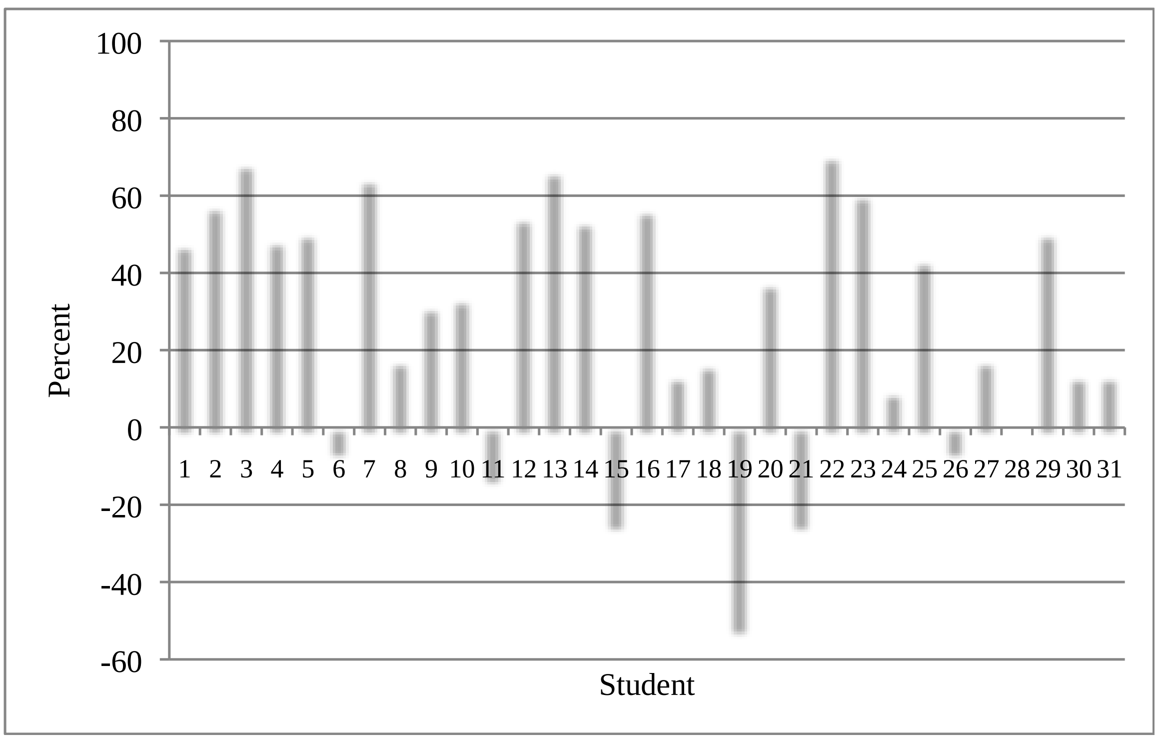

Figure 2. Non-treatment group Chemistry Skills Review Exam normalized gains, (*N*=31).

Overall, the mean for the treatment group on the Chemistry Skills Review Exam increased by 19.18%, from 63.93% on the pre-test, to 83.11% on the post-test. The standard deviation decreased from 18.37 to 9.24, and the range narrowed from 69% on the pre-test to 35% post-test (Figure 3). To compare the pre-treatment and post-treatment review exam results for the treatment group a paired t-test was conducted which resulted in a p-value of 0.0001, which is an extremely significant result. In response to a question related learning about these fundamental skills one student said, “At times it was a bit tedious, but it made a difference overall.”

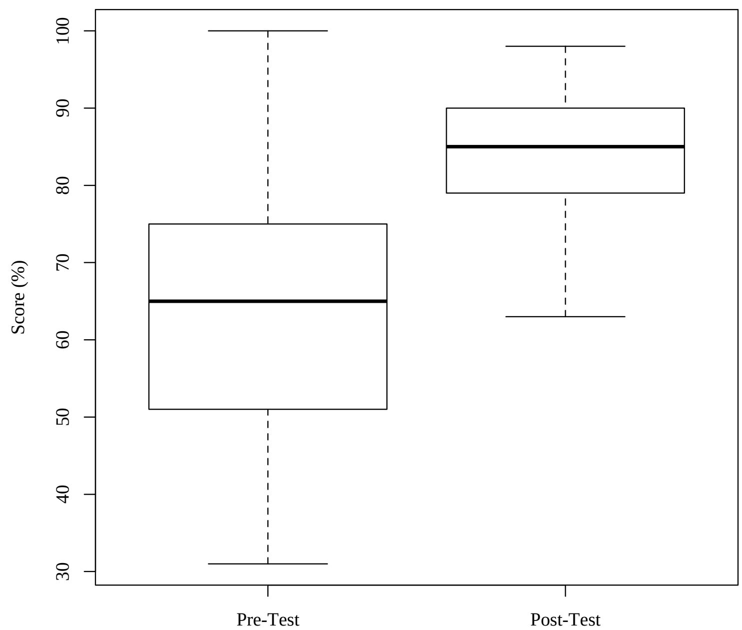

Figure 3. Treatment group Chemistry Skills Review Exam score distribution, (N=27).

For the non-treatment group the mean increased by 10.49%, from 67.16% to 77.65%. The standard deviation decreased from 20.35 to 15.42, and the range narrowed by 11% from 67% to 56% (Figure 4). To compare the pre-treatment and post-treatment review exam results for the non-treatment group a paired t-test was conducted which resulted in a p-value of 0.0002, which is a significant result.

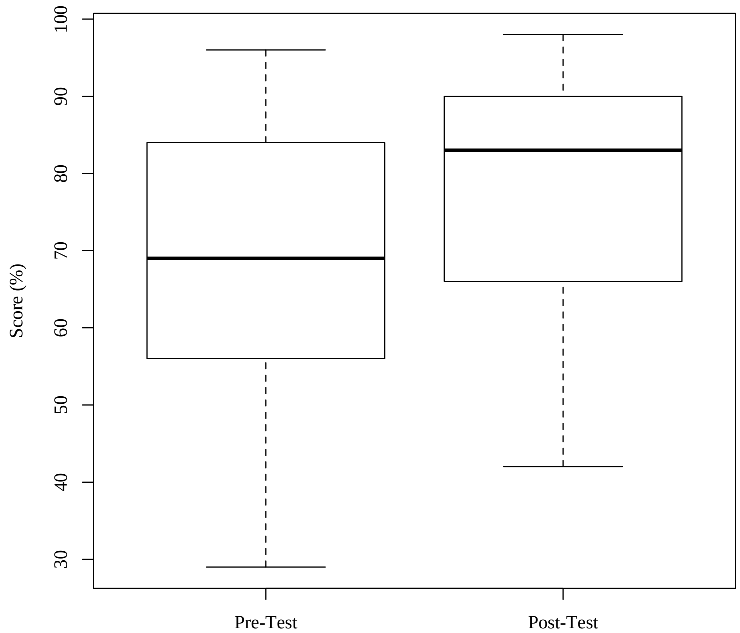

Figure 4. Non-treatment group Chemistry Skills Review Exam score distribution, (*N*=31).

There were seven statements that related specifically to chemistry on the Science Attitudes Survey. When these seven questions were analyzed using a Wilcoxon Signed Rank Test to compare how the ideas of the treatment group changed over the course of the study it was found that student responses to four statements showed a significant change and a rejection of the null hypothesis, and three resulted in the null hypothesis being accepted. For the non-treatment group, student responses to two statements showed significant change and five did not (Table 2).

Table 2
Wilcoxon Signed Rank Test p-values for Statements 1-7 of the Science Attitudes Survey

Statement	Treatment Group	Non-Treatment Group
I enjoy chemistry labs	0.01	0.17
I know how to use basic lab equipment effectively	0.001	0.03
I feel confident in my ability to acquire new lab skills	0.13	0.90
I'm an active participant in my lab group	0.85	0.78
I feel confident working in the lab	0.008	0.006
Lab work helps me understand theoretical chemistry concepts	0.02	0.52
I take lab work seriously	0.39	0.78

Note. Treatment group (*N*=20), and non-treatment group (*N*=20).

The pre-treatment and post-treatment student responses were also analyzed for differences between the treatment and non-treatment for statements 1-7 of the Science Attitudes Survey group using a Wilcoxon Paired Rank Test. For this part of the analysis there were no responses that were found to show a significant difference either pre-treatment or post-treatment. The test that resulted in the nearest to a significant result was the post-treatment Paired Rank Test for the statement, "Lab work helps me understand theoretical chemistry concepts." This statement had a p-value of 0.13 post-treatment when the treatment and non-treatment group's answers were compared (Table 3).

Table 3
Wilcoxon Paired Rank Test p-values for Statements 1-7 of the Science Attitudes Survey

Statement	Pre-Treatment	Post-Treatment
I enjoy chemistry labs	0.29	0.79
I know how to use basic lab equipment effectively	0.59	0.68
I feel confident in my ability to acquire new lab skills	0.92	0.25
I'm an active participant in my lab group	0.18	0.16
I feel confident working in the lab	0.29	0.99
Lab work helps me understand theoretical chemistry concepts	0.74	0.13
I take lab work seriously	0.91	0.47

Note. Treatment group (*N*=20), and non-treatment group, (*N*=20).

Overall, for the treatment group, the statement that resulted in the most significant difference as a result of the treatment was, I know how to use basic lab equipment effectively. Here the percent of student responses showed a 45% increase in strongly agree responses, a 35% decrease in agree responses, a decrease of 10% in neutral responses, and no change in disagree or strongly disagree responses (Figure 5). One student said, “My lab skills increased. So, for practical stuff the performance assessments helped.” Another student said, “When you know what you’re doing you’re more confident.” A third student said, “Instead of walking into the lab blind I knew what I was doing.”

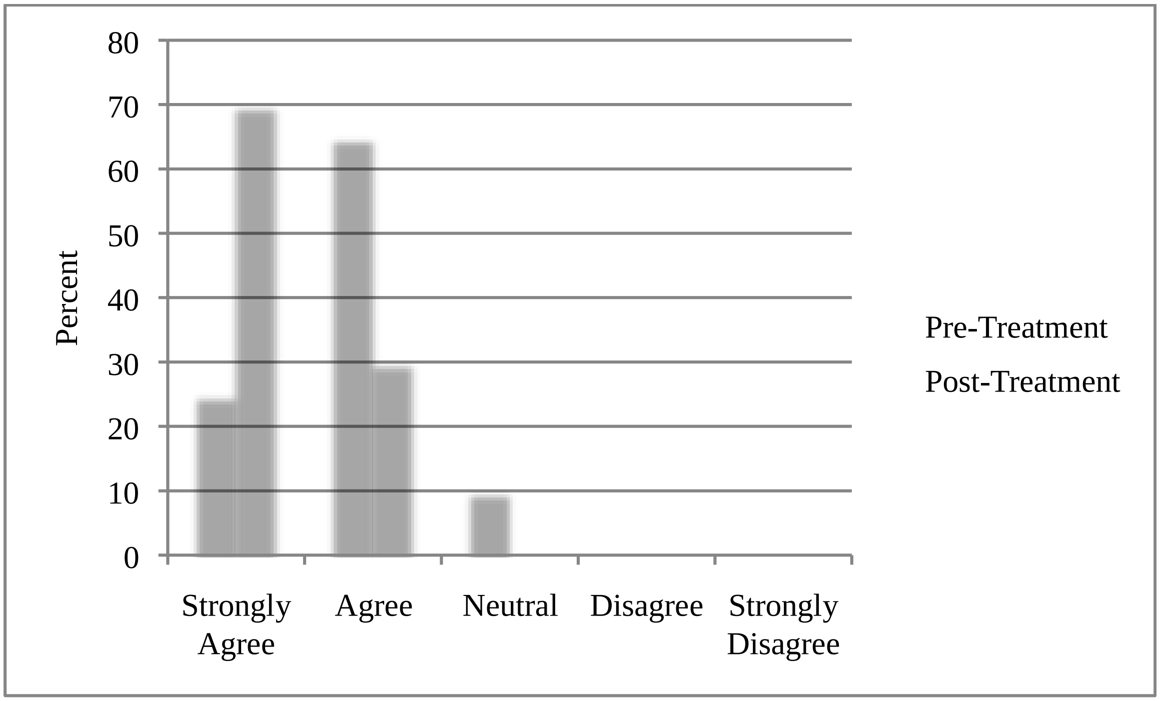

Figure 5. Survey statement: “I know how to use basic lab equipment effectively,” (*N*=20).

The second group of Likert items on the Science Attitudes Survey asked students to respond to six statements about their metacognitive techniques and study skills. Analyzing how students in both groups’ attitudes changed using the Wilcoxon Signed Rank Test revealed that the responses of the treatment group changed significantly over the course of the study for two of the statements, and four did not; whereas, for the non-treatment group student responses to none of the statements showed significant change (Table 4).

Table 4
Wilcoxon Signed Rank Test p-values for Statements 8-13 of the Science Attitudes Survey

Statement	Treatment Group	Non-Treatment Group
I regularly reflect over my own learning	0.02	0.35
I can identify those concepts that I understand and those that I do not	0.18	0.45
I try to find connections between what I'm learning in chemistry and my past experiences	0.16	0.81
There is a relationship between how hard I work and my grades	0.21	0.86
I'm aware of what studying strategies work best for me	0.04	0.19
I enjoy solving chemistry problems	0.34	0.82

Note. Treatment group (N=20), and non-treatment group, (N=20).

Student responses were analyzed for differences between the treatment and non-treatment groups for both the pre-treatment and post-treatment Science Attitudes Survey by using a Wilcoxon Paired Rank Test. The results of this test found that none of the responses were found to show a significant difference. Nearly significant was the result of the analysis for the pre-treatment survey statement, I regularly reflect over my own learning, which had a p-value of 0.05 (Table 5).

Table 5

Wilcoxon Paired Rank Test p-values for Statements 8-13 of the Science Attitudes Survey

Statement	Pre-Treatment	Post-Treatment
I regularly reflect over my own learning	0.05	0.25
I can identify those concepts that I understand and those that I do not	0.88	0.28
I try to find connections between what I'm learning in chemistry and my past experiences	0.16	0.88
There is a relationship between how hard I work and my grades	0.27	0.15
I'm aware of what studying strategies work best for me	0.09	0.25
I enjoy solving chemistry problems	0.30	0.22

Note. Treatment group (*N*=20), and non-treatment group, (*N*=20).

Overall, for the treatment group, the statement that resulted in the most significant difference as a result of the treatment was, I regularly reflect over my own learning. For this statement, the percent of student responses showed a 5% increase in strongly agree responses, a 25% increase in agree responses, a decrease of 20% in neutral responses, a decrease of 5% in disagree responses and no change in strongly disagree responses (Figure 6). One student said, "The lab skills self-assessment helped me to focus on what I didn't know. I had no clue about some of those things."

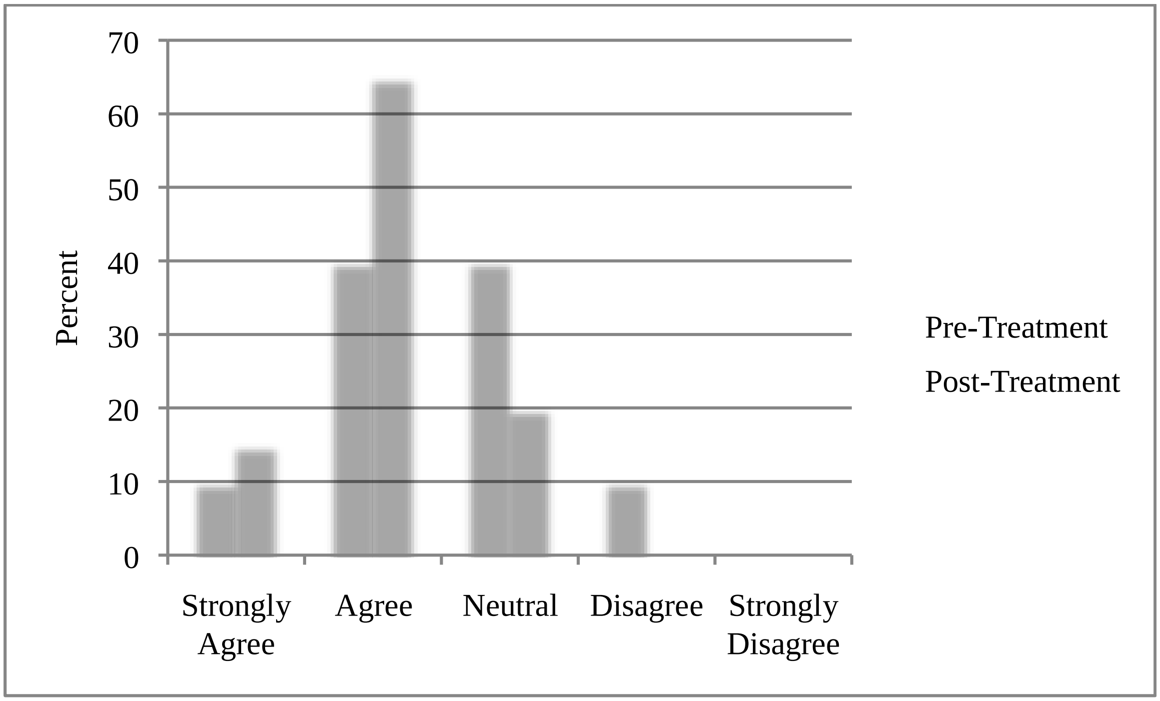

Figure 6. Survey statement, "I regularly reflect over my own learning," (*N*=20).

A second statement also resulted in a significant change in responses for the treatment group. This statement was, I'm aware of what studying strategies work for me. Here the percent of student responses showed a 35% increase in strongly agree responses, a 20% decrease in agree responses, a decrease of 5% in neutral responses, a decrease of 5% in disagree responses, and an increase of 5% in no change in strongly disagree responses (Figure 7). One student said, "I know that I prefer reading over my notes or reading the text rather than doing problems. But, sometimes it depends. For some topics doing problems works better." Another student said, "The quizzes in particular helped me to identify what I needed to work on."

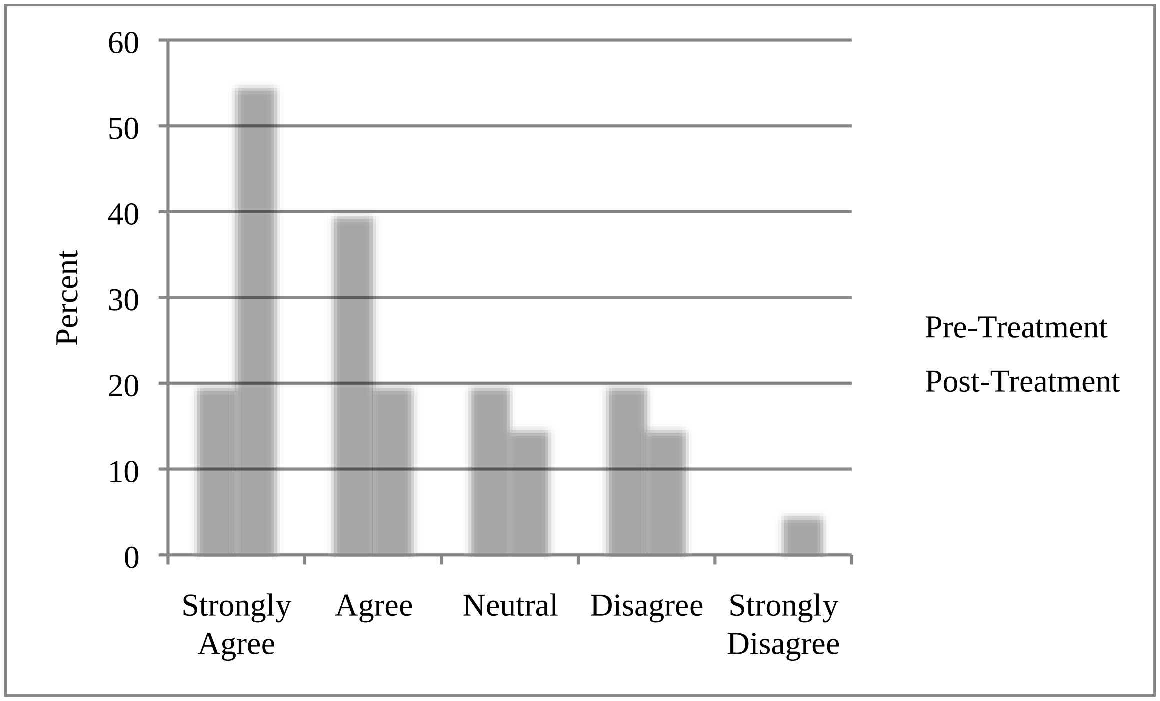

Figure 7. Survey statement: “I’m aware of what studying strategies work best for me,” (*N*=20).

There were four statements on the Science Attitudes Survey that had students respond to prompts about the place that chemistry has in their lives. Analyzing how students in both groups’ attitudes changed using the Wilcoxon Signed Rank Test revealed that the responses of the treatment group changed significantly over the course of the study for two statements, and two did not; whereas, for the non-treatment group student responses to none of the statements showed a significant change and (Table 6).

Table 6

Wilcoxon Signed Rank Test p-values for Statements 14-17 of the Science Attitudes Survey

Statement	Treatment Group	Non-Treatment Group
Chemistry is relevant to my everyday life	0.001	0.35
Learning chemistry changes my ideas about how the world works	0.14	0.48
I can see connections between what I learn in chemistry to my other classes	0.03	0.71
I have thought about taking chemistry classes after high school, or even pursuing a career in chemistry	0.59	0.67

Note. Treatment group (*N*=20), and non-treatment group, (*N*=20).

Student responses pre-treatment and post-treatment were analyzed for differences between the treatment and non-treatment group using a Wilcoxon Paired Rank Test. The test results were that none of the responses were found to show a significant difference. The statement, chemistry is relevant to my everyday life, had a near significant result with a p-value of 0.07 (Table 7).

Table 7

Wilcoxon Paired Rank Test p-values for Statements 14-17 of the Science Attitudes Survey

Statement	Pre-Treatment	Post-Treatment
Chemistry is relevant to my everyday life	0.07	0.68
Learning chemistry changes my ideas about how the world works	0.51	0.57
I can see connections between what I learn in chemistry to my other classes	0.09	0.86
I have thought about taking chemistry classes after high school, or even pursuing a career in chemistry	0.21	0.18

Note. Treatment group (*N*=20), and non-treatment group, (*N*=20).

For the treatment group, the statement that resulted in the greatest difference as a result of the treatment was, chemistry is relevant to my everyday life. Here the percent of student responses showed a 5% increase in strongly agree responses, a 30% increase in agree responses, a decrease of 25% in neutral responses, a decrease of 5% of disagree responses, and a decrease of 5% in strongly disagree responses (Figure 8). One student said, “It’s beneficial to see what we’re learning put into action.”

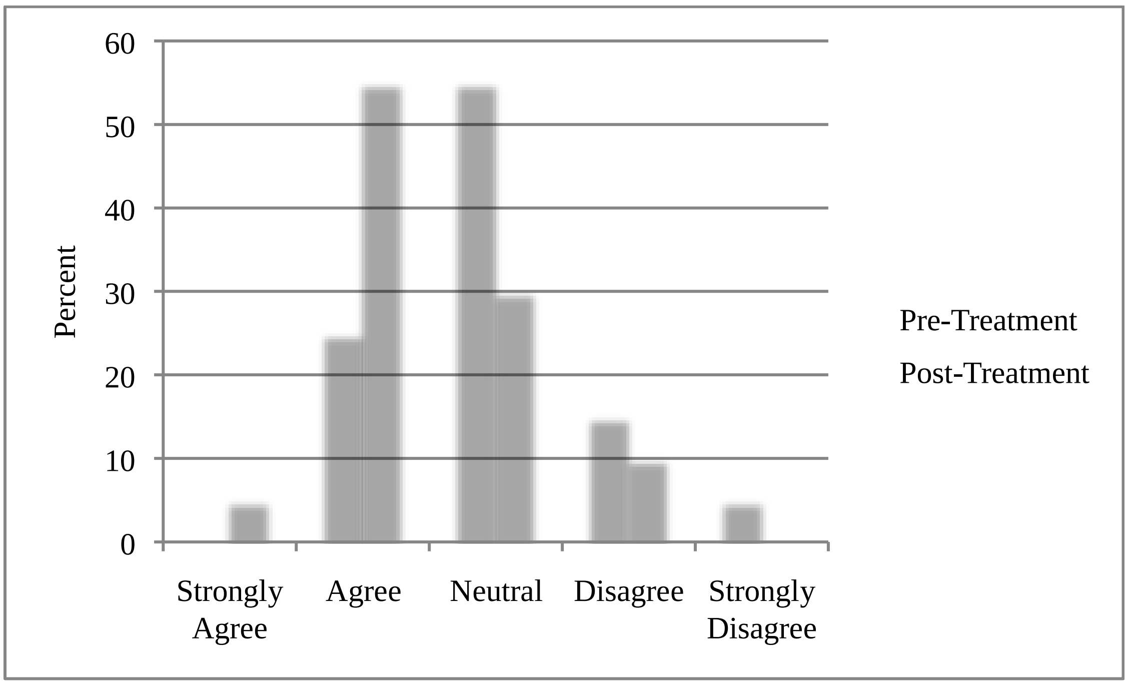

Figure 8. Survey statement: “Chemistry is relevant to my everyday life,” (*N*=20).

The treatment group and the non-treatment group completed the Chemistry Lab Skills Self-Assessment before and after the unit of study. Students rated their own skill level on the use of the electronic balance, graduated cylinder, Bunsen Burner, pipetting, and performing a titration. Responses were a 3 for exemplary, a 2 for proficient, and 1 for needs improvement. The means for each skill were calculated pre-treatment and post-treatment, as were normalized gains for each skill and the average normalized gain for each group.

The treatment group saw the average score for each of the five skills increase (Table 8). The skill with the greatest increase was titrating, which increased by 1.30 from 1.22 to 2.52. The skill with the greatest normalized gain was using the electronic balance. For this skill, all students assessed their own competency as exemplary, and the normalized gain was 100%. The average normalized gain across all five skills was 78.50%. Overall, the effect on students' assessment of their own skill level increased throughout the course of the study. One student said, "The performance assessments made me more aware of what was going on." Another student said, "They made me pay more attention to particular details."

Table 8
Chemistry Lab Skills Self-Assessment Means for the Treatment Group

Self-Assessment	Electronic Balance	Graduated Cylinder	Bunsen Burner	Pipetting	Titration
Pre-treatment	2.44	2.59	1.74	1.41	1.22
Post-treatment	3.00	2.85	2.89	2.44	2.52
Normalized Gain	100	63.41	91.27	64.78	73.03

Note. Treatment group, (*N*=27).

The non-treatment group saw the average score for each of the five skills increase (Table 9). The skill with the greatest increase was titration, which increased from a mean score of 1.13 to 2.32. The skill with the greatest normalized gain was measuring mass with the electronic balance with a value of 64.62%. The average normalized gain across all five skills was 50.92%. Overall, the effect on students' assessment of their own skill level increased throughout the course of the study even though they did not receive the additional instruction or complete any performance assessments like the treatment group did.

Table 9
Chemistry Lab Skills Self-Assessment Means for the Non-Treatment Group

Self-Assessment	Electronic Balance	Graduated Cylinder	Bunsen Burner	Pipetting	Titration
Pre-treatment	2.35	2.61	2.13	1.71	1.13
Post-treatment	2.77	2.84	2.48	2.06	2.32
Normalized Gain	64.62	58.97	40.23	27.13	63.64

Note. Non-treatment group, (*N*=31).

The treatment group had a greater normalized gain for each of the five lab-skills than the non-treatment group. The skill where there was the greatest difference was using the Bunsen Burner. Here the treatment group had a normalized gain of 91.27% while the non-treatment group had a normalized gain of 40.23%. This is a difference of 51.04%. Pipetting showed the second greatest difference in the normalized gains with a difference of 37.65%. Using the electronic balance had the treatment group score 35.38% higher than the non-treatment group's normalized gain. The difference in titration normalized gains was small at 9.39%. The least difference was regarding the use of the graduated cylinder which only had a difference in the normalized gains of 4.44% (Figure 9).

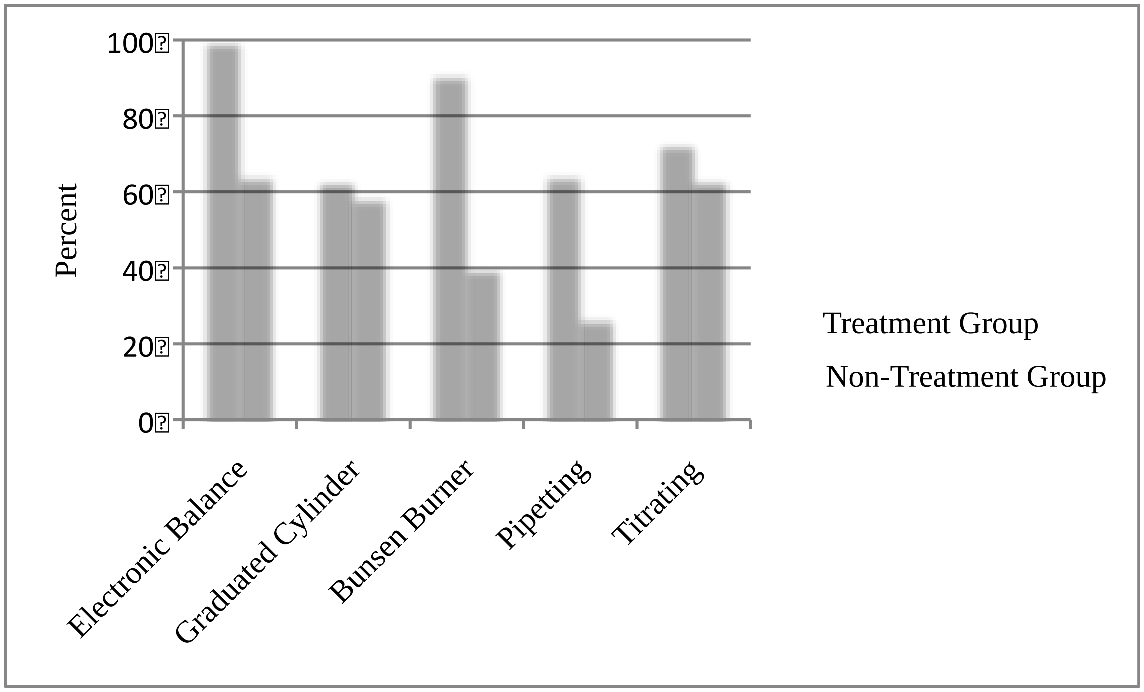

Figure 9. Normalized gains for 5 lab skills for the treatment group, (*N*=27) and the non-treatment group, (*N*=31).

During the unit of study both the treatment and the non-treatment group wrote three formative quizzes. The first quiz was on gravimetric stoichiometry, the second on solution stoichiometry and the third on gas stoichiometry. At the end of the unit of study both groups also wrote a summative unit exam.

On the Gravimetric Stoichiometry Quiz the treatment group had a mean of 72.12% with a standard deviation of 20.79 and a range of 75% (*N*=26). The non-treatment group had a mean score of 68.93% with a standard deviation of 24.37 and a range of 75% (*N*=30). The two-tailed unpaired t-test had a p-value of 0.60. This result is not considered to be statistically different.

The second formative quiz was the Solution Stoichiometry Quiz. Here the treatment group had a mean score of 73.78% with a standard deviation of 24.77 and a range of 90% (*N*=27). The non-treatment group had a mean of 70.18% with a standard deviation of 25.79 and a range of 90% (*N*=28). The two-tailed unpaired t-test had a p-value of 0.60, which is not considered statistically significant.

The final formative quiz of the unit was the Gas Stoichiometry Quiz. The treatment group had a mean of 73.85% with a standard deviation of 21.89 and a range of 69% (*N*=26). The non-treatment group had a mean of 65.17% with a standard deviation of 23.45 and a range of 75% (*N*=30). The two-tailed unpaired t-test had a p-value of 0.16 which is not considered statistically significant.

At the end of the unit of study both groups wrote the Stoichiometry Summative Unit Exam. The treatment group had a mean of 76.44% with a standard deviation of 17.98 and a range of 69% (*N*=27). The non-treatment group had a mean of 73.61% with a standard deviation of 17.51 and a range of 64% (*N*=31). The p-value calculated by doing an unpaired two-tailed t-test was 0.55. This result is not considered to be statistically significant.

The non-treatment group had a mean score of 67.16% on the pre-treatment Chemistry Skills Review Exam while the treatment group had a mean of 63.93%. This is a difference of 3.23%. For all subsequent assessments, the treatment group had higher mean scores than the non-treatment group. On the Gravimetric Stoichiometry Quiz the difference was 3.19%. The difference on the Solution Stoichiometry Quiz was 3.60%. For the Gas Stoichiometry Quiz the difference was 8.68%. On the Stoichiometry Unit Exam, the treatment group had a mean score 2.83% higher than the non-treatment group. Finally, on the post-treatment Chemistry Skills Review Exam the treatment group had a mean score 5.46% greater than the non-treatment group (Figure 10).

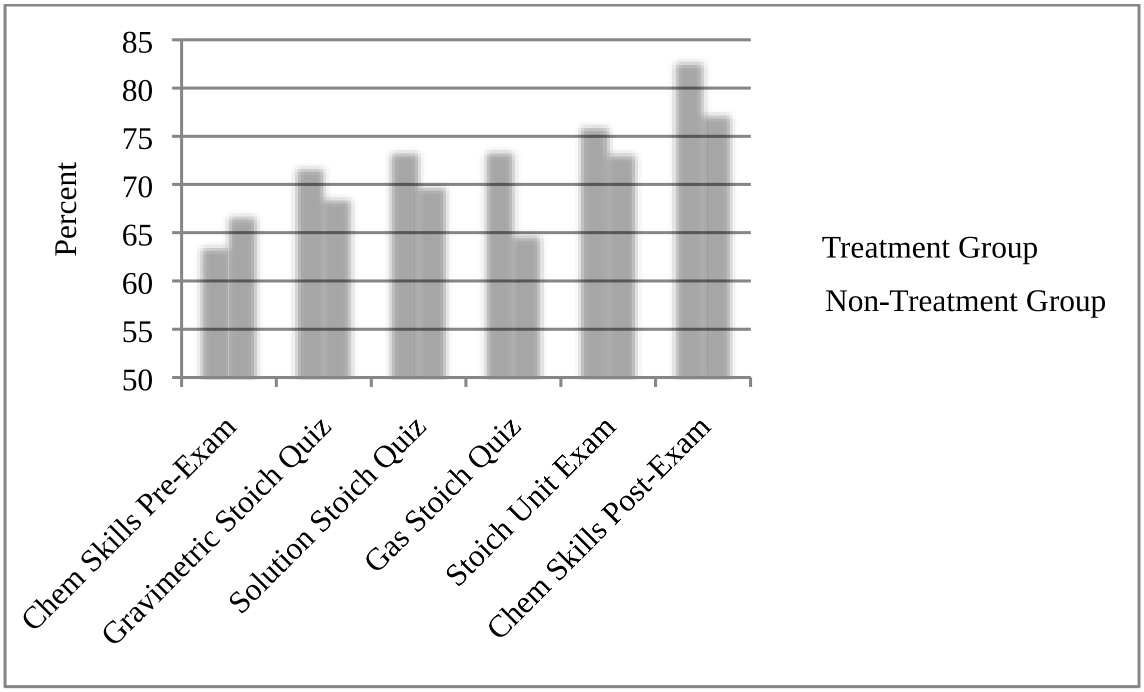

Figure 10. Assessment item means for the treatment group (*N*=27), and the non-treatment group, (*N*=31).

INTERPRETATION AND CONCLUSION

This study had a meaningful effect upon the ability of my students to perform basic lab skills, and upon their confidence using those skills. Spending time giving explicit instruction in how to perform the skills and then following up by conducting performance assessments was an effective technique. Even though both the treatment group and the non-treatment group had positive average normalized gains across all five skills the treatment group outperformed the non-treatment group consistently by a decent margin. The non-treatment group's average normalized gain was 50.92%, while the treatment group's was 78.50%. This is a difference of 27.58%. This validates the energy and effort that the students, and I, put in with these tasks, and I feel confident in concluding that the treatment that I delivered had a real and tangible effect on my students' abilities, and their confidence, working in the lab.

Two of the questions on the Science Attitudes Survey showed a significant change in student attitudes about the chemistry lab in the treatment group, but not in the non-treatment group. They were, I enjoy chemistry labs, and, Lab work helps me to understand theoretical chemistry concepts. Because this change in attitude appeared in the treatment group and not in the non-treatment group indicates that the development of improved lab skills led to a more positive attitude toward the lab. If students feel more comfortable with the techniques demanded by the lab, then they can focus more on the theoretical concepts at work during an experiment, and as a result can have a better experience. I feel confident in saying that the performance assessments had a significant role in enhancing student attitudes toward the chemistry lab.

Two questions on the Student Attitudes Survey in relation to chemistry in general showed a significant change for the treatment group, but not for the non-treatment group. These questions were, Chemistry is relevant to my everyday life, and, I can see connections between what I learn in chemistry to my other classes. I was hoping that working on improving student's perceptions of the chemistry lab would carry over to changing student attitudes toward chemistry in general, and I am happy to see that students were making broader connections between the content of the course and their lives and other studies; however, I am not sure that there is a direct relationship between the treatment and these changes in attitude. Future study on ways to help students make the connection between the classroom and their lives would be a valuable way to delve deeper into this issue.

Two of the questions that showed a significant change related to student levels of metacognition in the treatment group. These questions were, I regularly reflect over my own learning, and, I'm aware of what studying strategies work for me. I was trying to promote a metacognitive attitude in my students through the use of the Chemistry Lab Skills Self-Assessment; however, I have doubts about the degree to which the treatment that I delivered is responsible for this change. Although I was pleased to see this change in attitude, it is likely that other factors were at play that are ultimately responsible for the movement in students' perception of their metacognitive level. Metacognition is an important skill to help students develop, and would be an interesting avenue for additional study.

In terms of academics, the treatment group showed an increase of 19.18% in their average score on the Chemistry Skills Review Exam pre- and post-treatment, whereas the non-treatment group increased their average score 10.49%. In addition, the treatment group went from an average 3.23% below the non-treatment group on the pre-treatment exam, to an average of 5.46% greater than the non-treatment group on the post-treatment exam. This is a swing of 8.69%. Although not statistically significant, that the treatment group went from a lower average to a greater one on this exam is encouraging to me. It is likely that this result was not directly a result of the treatment in isolation; the building of relationships and the positive classroom climate that arose because of the treatment probably played a role too. Across all of the assessments there was a consistent upward trend for the treatment group, while the non-treatment group showed some fluctuations.

Finally, one result that stands out academically are the scores on the summative unit exam. The treatment group had a slightly higher average than the non-treatment group. This is important to me because the non-treatment group had multiple classes of time to work on theoretical problems and traditional practice questions, while the treatment group was completing their performance assessments. In a way, the treatment group had less time to work on problems and worksheets, and instead had extra tasks to do, and yet their results were better. So, even though the differences between the scores on all of the quizzes and exams between the two groups were not statistically significant I do think that there was a real academic benefit to the treatment group as a result of the lab skill performance assessments that they completed.

VALUE

This action research project has had a profound effect on me and my classroom. I have come to see how useful laboratory skills performance assessments are for fostering the development of lab skills. The progress that I saw in my students was rewarding for me and validated and justified the time that I spent on directly teaching lab skills and through the process of conducting individual performance assessments. I was able to work the performance assessments into my curriculum quite smoothly, and in spite of how time consuming they were, I don't feel like they caused me to rush through other content, or that I had to make other sacrifices or modifications to my unit plan. I will absolutely continue to integrate the use of performance assessments for the five lab skills from this action research into my regular delivery of Chemistry 20. I have come to truly appreciate performance assessments as a formative assessment technique. As a result, this project has encouraged me to find other lab skills whose development I could promote through the use of performance assessments, both for future Chemistry 20 classes, but also for the other classes that I teach like grade 10 general science and Chemistry 30. However, more than that I have realized that performance assessments are a great tool for me to use to build relationships with my students and to promote a positive perception of the chemistry laboratory.

This study pushed me out of my comfort zone and opened up avenues of instruction and assessment that I had not used in my classroom before. I had always used labs in my pedagogy but I had never focused specifically on skills. Also, I had never completed any performance assessments prior to this action research. By engaging in this study, I got to interact with my students in a whole new way. The dynamic that it created in the classroom was nothing but positive. Being able to offer specific instruction in a skill and then to go to the lab and spend time with each individual student, on multiple occasions, to check their competency, built up relationships in a way that was rewarding and that continued away from the lab and back in the classroom. It promoted the idea that we were all in it together and was a great way to show students tangible and practical progress in their development as students and chemists.

I am motivated to take my use of performance assessments beyond basic lab skills and to work on incorporating even more authentic and challenging lab work into my unit plans. I would like to do a performance assessment of an investigation where students have to follow the full scientific process. A contextualized activity based on a real-world scenario where students have to analyze a problem, design and conduct an experiment, gather data and communicate their results would be a great way for me to move my use of performance assessments forward and would work as an instructional technique to further enhance student learning.

As an experienced teacher, I can sometimes forget the difficulties that some of my students may face when confronted with lab work. This research project has forced me to be a more reflective teacher, made me more cognizant of my methods and had me re-evaluate how I think about lab work and the place that it occupies in my curriculum. In the past, I have viewed the lab as a place to reinforce and to support the learning that goes on in the classroom; however, I have come to appreciate the unique opportunities for instruction that are present in the lab. As a result of this, I have become open to the idea that the classroom can support the learning that goes on in the lab just as much as the lab can support the learning of the classroom. The mutual support between the lab and the classroom is a dynamic that I have recognized because of my research and is one that I plan to continue to explore and develop.

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APPENDICES

APPENDIX A

IRB EXEMPTION APPROVAL

INSTITUTIONAL REVIEW BOARD

For the Protection of Human Subjects
FWA 00000165

MONTANA STATE UNIVERSITY

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Administrator:
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MEMORANDUM

TO: Tyler Buchan and John Graves

FROM: Mark Quinn *Mark Quinn CJ*

DATE: September 19, 2017

SUBJECT: *"The Effect of Laboratory Skills Performance Assessments on Chemistry Attitudes and Achievement"* [TB091917-EX]

The above research, described in your submission of September 19, 2017, 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:

_X_ (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.

_X_ (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.

APPENDIX B

CHEMISTRY SKILLS REVIEW EXAM

Chemistry 20
Chemistry Skills Review Exam

Name: ___________________________

1. State the number of significant digits in each of the following:

   a. 0.250 ______________________

   b. 3.004 ______________________

   c. 695 ______________________

   d. 0.007 ______________________

2. Express each of the following in its opposite notation (standard or scientific).

   a. 0.00036 ______________________

   b. 483000 ______________________

   c. 7.2×10^{-4} ______________________

   d. 5.82×10^{3} _____________________

3. State the corresponding name or chemical formula for each of the following:

   a. Na_2O ______________________

   b. $Ca_3(PO_4)_2$ ______________________

   c. Iron (iii) chloride ______________________

   d. Magnesium nitrate ______________________

4. Balance each of the following chemical equations:

   a. ______ Al + ______ F_2 → ______ AlF_3

   b. ______ $Ca(NO_3)_2$ + ______ Li_3PO_4 → ______ $Ca_3(PO_4)_2$ + ______ $LiNO_3$

   c. ______ C_3H_8 + ______ O_2 → ______ CO_2 + ______ H_2O

5. Predict the products and balance each of the following chemical reactions:

   a. Sodium reacts with zinc oxide

   b. Copper (ii) sulfate reacts with aluminum carbonate

6. Calculate the molar mass of each of the following compounds:

   a. H_2O

   b. $KClO_3$

   c. $Ni_2(SO_4)_3$

7. Calculate moles for each of the following chemicals.

   a. 50.0 g of NaCl

   b. 25.0 g of magnesium nitrate

APPENDIX C

CHEMISTRY SKILLS REVIEW EXAM II

Chemistry 20
Chemistry Skills Review Exam II

Name: ___________________________

1. State the number of significant digits in each of the following:

   a. 0.0340 ______________________

   b. 700 ________________________

   c. 6.88×10^7 __________________

   d. 0.05 ________________________

2. Express each of the following in its opposite notation (standard or scientific).

   a. 47000 ________________________

   b. 0.000085 ______________________

   c. 6.3×10^3 ______________________

   d. 2.97×10^{-2} ______________________

3. State the corresponding name or chemical formula for each of the following:

   a. Ag_2O ______________________

   b. $Fe_3(PO_4)_2$ ______________________

   c. Copper (ii) fluoride ______________________

   d. Zinc sulfate ______________________

4. Balance each of the following chemical equations:

a. ______ Fe + ______ Cl_2 $\rightarrow$ ______ $FeCl_3$

b. ______ $Zn(ClO_3)_2$ + ______ Li_3PO_4 $\rightarrow$ ______ $Zn_3(PO_4)_2$ + ______ $LiClO_3$

c. ______ C_2H_6 + ______ O_2 $\rightarrow$ ______ CO_2 + ______ H_2O

5. Predict the products and balance each of the following chemical reactions:

a. Hydrochloric acid reacts with magnesium hydroxide

b. Aluminum nitrate reacts with calcium sulfate

6. Calculate the molar mass of each of the following compounds:

a. NH_3

b. $AgNO_3$

c. $Fe_2(CO_3)_3$

7. Calculate moles for each of the following chemicals.

   a. 26.0 g of Li_3N

   b. 50.0 g of zinc sulfite

APPENDIX D

SCIENCE ATTITUDES SURVEY

Chemistry 20
Science Attitudes Survey

Participation in this survey is voluntary and you can choose to not answer any question that you don't want to answer, and you can stop this survey at any time.
Your participation or non-participation will not affect your grade or your class standing in any way.

This survey is to help both of us understand what you think about your chemistry skills. Please rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

---

1. I enjoy chemistry labs.

   1 2 3 4 5

2. I know how to use basic lab equipment effectively.

   1 2 3 4 5

3. I feel confident in my ability to acquire new lab skills.

   1 2 3 4 5

4. I'm an active participant in my lab group.

   1 2 3 4 5

5. I feel confident working in the lab.

   1 2 3 4 5

6. Lab work helps me to understand theoretical chemistry concepts.

   1 2 3 4 5

7. I take lab work seriously.

   1 2 3 4 5

8. I regularly reflect over my own learning.

   1 2 3 4 5

9. I can identify those concepts that I understand and those that I do not.

   1 2 3 4 5

10. I try to find connections between what I'm learning in chemistry and my past experiences.

    1 2 3 4 5

11. There is a relationship between how hard I work and my grades.

    1 2 3 4 5

12. I'm aware of what studying strategies work best for me.

    1 2 3 4 5

13. I enjoy solving chemistry problems.

    1 2 3 4 5

14. Chemistry is relevant to my everyday life.

    1 2 3 4 5

15. Learning chemistry changes my ideas about how the world works.

    1 2 3 4 5

16. I can see connections between what I learn in chemistry to my other classes.

    1 2 3 4 5

17. I have thought about taking chemistry classes after high school, or even pursuing a career in chemistry.

    1 2 3 4 5

APPENDIX E

CHEMISTRY LAB SKILLS SELF-ASSESSMENT

Chemistry 20
Chemistry Lab Skills Self-Assessment

Please asses your skill level for the following laboratory skills.

1: Needs Improvement; 2: Proficient; 3: Exemplary

1. Measuring mass using an electronic balance.

   - ○ 1
   - ○ 2
   - ○ 3

2. Measuring volume using a graduated cylinder.

   - ○ 1
   - ○ 2
   - ○ 3

3. Lighting a Bunsen burner.

   - ○ 1
   - ○ 2
   - ○ 3

4. Measuring volume using a pipet.

   - ○ 1
   - ○ 2
   - ○ 3

5. Performing a titration.

   - ○ 1
   - ○ 2

○ 3

APPENDIX F

ELECTRONIC BALANCE PERFORMANCE ASSSESSMENT RUBRIC

Chemistry 20
Electronic Balance Performance Assessment Rubric

Students are asked to weigh out 0.60 g of sodium chloride using an electronic balance.

The student:

- ○ Knows how to turn on the scale
- ○ Uses a weigh-boat
- ○ Zeroes the scale
- ○ Measures out the prescribed mass accurately

The student can effectively use an electronic balance:

- ○ Yes
- ○ No

APPENDIX G

GRADUATED CYLINDER PERFORMANCE ASSESSMENT RUBRIC

Chemistry 20
Graduated Cylinder Performance Assessment Rubric

Students are asked to measure out 40.0 mL of water using a 50.0 mL graduated cylinder.

The student:

- ○ Doesn't pour directly from the bottle into the cylinder
- ○ Knows how to read the meniscus in the graduated cylinder
- ○ Uses an eye dropper
- ○ Measures out the prescribed volume accurately

The student can effectively use a graduated cylinder:

- ○ Yes
- ○ No

APPENDIX H

BUNSEN BURNER PERFORMANCE ASSESSMENT RUBRIC

Chemistry 20
Bunsen Burner Performance Assessment Rubric

Students are asked to light a Bunsen Burner.

The student:

- ○ Turns on the main line gas
- ○ Knows how to use the gas valve on the Bunsen Burner
- ○ Effectively uses the sparker
- ○ Uses the oxygen supply control
- ○ Produces a blue in blue flame

The student can effectively light a Bunsen Burner:

- ○ Yes
- ○ No

APPENDIX I

PIPETTING PERFORMANCE ASSESMENT RUBRIC

Chemistry 20
Pipetting Performance Assessment Rubric

Students are asked to measure a 2.0 mL and 4.0 mL of copper (ii) sulfate using a pipet.

The student:

- ○ Doesn't pipet directly out of the bottle
- ○ Knows how to read volumes on the pipet
- ○ Uses correct pipetting technique

The student can effectively measure volumes using a pipet:

- ○ Yes
- ○ No

APPENDIX J

TITRATION PERFORMANCE ASSESSMENT RUBRIC

Chemistry 20
Titration Performance Assessment Rubric

Students are asked to titrate a prescribed volume of acid with a base until the endpoint is reached.

The student:

- ○ Correctly uses the graduated cylinder to measure the sample of acid
- ○ Adds an indicator to the sample
- ○ Doesn’t fill the buret directly from the bottle
- ○ Uses a funnel while filling the buret
- ○ Knows how to read volume on a buret
- ○ Stops adding titrant reasonably close to the endpoint
- ○ Correctly reports the volume of titrant added

The student can effectively perform a titration:

- ○ Yes
- ○ No

APPENDIX K

GRAVIMETRIC STOICHIOMETRY QUIZ

Chemistry 20
Gravimetric Stoichiometry Quiz

Name: ______________________

Watch your units and significant digits! Write balanced equations!

1. Phosphorous reacts with oxygen from the air to form solid tetraphosphorous dioxide. Determine how many moles of oxygen are required to react with 1.325 mol of phosphorous.

2. Determine the number of moles of phosphoric acid that are required to completely react with 15.7 g of magnesium hydroxide.

3. Determine the mass of precipitate that will form when 2.55 mol of calcium nitrate reacts with an excess amount of aluminum sulfate.

4. Calculate the mass of solid silver that will be produced when 76.0 g of zinc reacts with excess silver nitrate.

APPENDIX L

SOLUTION STOICHIOMETRY QUIZ

Chemistry 20
Solution Stoichiometry Quiz

Name: ______________________

Watch your units and significant digits! Write balanced equations!

1. Determine the volume of 0.700 mol/L aqueous magnesium chloride that must be added to 50.0 mL of 0.300 mol/L aqueous silver nitrate in order to remove all of the chloride ions.

2. Determine the concentration of 500 mL of sulfuric acid that can be neutralized by adding 225 mL of 0.385 mol/L ammonium hydroxide.

3. Calculate the minimum mass of sodium carbonate that must be added to 60.0 mL of a 0.100 mol/L aqueous solution of barium nitrate in order to precipitate all of the barium ions.

4. Hydrochloric acid reacts with pure magnesium carbonate according to the following equation:

$$MgCO_3 \ + \ 2HCl \ \rightarrow \ MgCl_2 \ + \ H_2O \ + \ CO_2$$

Calculate the volume of 0.280 mol/L hydrochloric acid that is needed to react with 1.65 g of pure magnesium carbonate.

5. A solid piece of magnesium metal is placed in a 0.500 mol/L solution of hydrochloric acid. The initial mass of the metal is 15.0 g and after the reaction is complete the mass of the metal determined to be 11.85 g. Determine the volume of the acid that reacted.

APPENDIX M

GAS STOICHIOMETRY QUIZ

Chemistry 20
Gas Stoichiometry Quiz

Name: ________________________

Watch your units and significant digits! Write balanced equations!

1. Determine the mass of water vapour that will be produced when 1.64 L of oxygen gas at 38.0 ^{O}C and 245 kPa completely reacts with excess hydrogen gas.

2. Diborane, B_2H_6, gas can be burned in oxygen to form boron (iii) oxide and water vapour. Determine the resulting water vapour pressure in a 10.0 L container at a temperature of 25.0 ^{O}C if 10.0 g of boron (iii) oxide is produced.

3. Lead (ii) sulfide is burned in oxygen to produce lead (ii) oxide and sulfur dioxide. Calculate the volume of oxygen that will be consumed when 80.0 g of lead (ii) sulfide reacts with oxygen at 1000 ^{O}C and 200 kPa.

4. Given the following information, determine the molar concentration of the solution of potassium permanganate:

Titration of 10.0 mL of Acidified 0.100 mol/L $FeSO_4$ with $KMnO_4$

Trial	**1**	**2**	**3**	**4**
Final buret reading (mL)	11.3	21.9	32.5	43.1
Initial buret reading (mL)	0.1	11.3	21.9	32.5
Volume of $KMnO_4$ added (mL)	11.2	10.5	10.6	10.6

$$10FeSO_{4(aq)} + 2KMnO_{4(aq)} + 8H_2SO_{4(aq)} \rightarrow 5Fe_2(SO_4)_{3(aq)} + K_2SO_{4(aq)} + 2MnSO_{4(aq)} + 8H_2O_{(l)}$$

APPENDIX N

STOICHIOMETRY UNIT EXAM

Chemistry 20
Stoichiometry Unit Exam

Name: ___________________________

Part I – Multiple Choice

Please indicate your response on the scantron. You can write on this exam!

1. In a chemical analysis the reactant that is **completely consumed** is called the:
    a. Excess reactant
    b. Limiting reactant
    c. Titrant
    d. Filtrate

2. The amount of **magnesium** in a 72.9 mg strip is:
    a. 0.333 mmol
    b. 3.00 mmol
    c. 7.29 mmol
    d. 1.77 mol

3. When 100 g of carbon (charcoal) is burned in a barbeque to produce carbon dioxide, the **mass** of oxygen required is:
    a. 100 g
    b. 266 g
    c. 424 g
    d. 1.22 kg

4. If 15.9 g of zinc is reacted with aqueous silver nitrate, and 5.4 g of zinc is left after the reaction, the **silver nitrate** could be described as the:
    a. Limiting reactant
    b. Excess reactant
    c. Precipitate
    d. Catalyst

5. Titanium (molar mass = 48 g/mol) reacts with oxygen to form titanium oxide, TiO_2. How many **grams** of TiO_2 can be prepared from 7.2 g of titanium **and** 7.2 g of oxygen?
    a. 6.3 g
    b. 9.6 g
    c. 12.0 g
    d. 14.4 g

6. Gasoline antifreeze (methyl-hydrate) is added to automobile gas tanks in winter to allow for cleaner combustion of water-contaminated gasoline. The IUPAC name for methyl-hydrate, also called wood alcohol, is methanol. The chief reaction by which methanol is manufactured is:

$$CO_{(g)} + 2H_{2(g)} \rightarrow CH_3OH_{(l)}$$

If 70.0 kg of $CO_{(g)}$ are used in combination with 9.00 kg of $H_{2(g)}$, the **limiting reactant(s)** is/are:
   a. $CO_{(g)}$ and $H_{2(g)}$
   b. $CH_3OH_{(l)}$
   c. $CO_{(g)}$
   d. $H_{2(g)}$

7. How many **moles** of oxygen gas are needed to react with one mole of lactic acid, $C_3H_6O_{3(aq)}$, to form carbon dioxide gas and water?
   a. 3
   b. 6
   c. 9
   d. 12

8. Hydrochloric acid, is produced in the stomach to aid in the breakdown of food. Excess stomach acid, however, can irritate the lower esophagus causing heartburn. Milk of Magnesia, a suspension of $Mg(OH)_{2(s)}$ in water, can provide effective relief from heartburn pain in most cases. How many **moles** of stomach acid are neutralized for every mole of magnesium hydroxide in Milk of Magnesia?
   a. 1
   b. 2
   c. 3
   d. 4

9. One method of producing oxygen in the lab is by the decomposition of potassium chlorate according to the equation:

$$2KClO_{3(s)} \rightarrow 2KCl_{(S)} + 3O_{2(g)}$$

What is the maximum amount of **oxygen gas** that can be prepared from 5.00 g of $KClO_{3(s)}$?
   a. 1.30 g
   b. 1.96 g
   c. 2.60 g
   d. 3.92 g

10. If 0.203 g of titanium metal is completely reacted with chlorine gas to form 0.805 g of a compound containing **only** titanium and chlorine, then what is its formula?
    a. $TiCl_2$
    b. $TiCl_3$
    c. $TiCl_4$
    d. $TiCl_5$

11. A student set up the following data table for the decomposition of iron (iii) oxide.

    $$2Fe_2O_{3(s)} \rightarrow 4Fe_{(s)} + 3O_{2(g)}$$

Mass of iron (iii) oxide decomposed	Mass of iron produced	Mass of oxygen produced
2.00 g		

    When the student completes the data table, the student correctly states that the **mass of iron** produced should be:
    a. Less than the mass of oxygen produced
    b. Twice the mass of iron (iii) oxide decomposed
    c. The same as the mass of iron (iii) oxide decomposed
    d. Greater than the mass of oxygen produced

12. The amount of hydrochloric acid in 15 mL of 6.0 mol/L is:
    a. 0.40 mmol
    b. 2.5 mmol
    c. 3.3 mmol
    d. 90 mmol

13. The progressive addition of a solution from a **buret** into a measured volume of a sample solution is called:
    a. Crystallization
    b. Filtration
    c. Stoichiometry
    d. Titration

14. The etching of copper metal is easily done with nitric acid, according to the following equation:

$$Cu_{(s)} + 8HNO_{3(aq)} \rightarrow 3Cu(NO_3)_{2(aq)} + 2NO_{(g)} + 4H_2O_{(l)}$$

Predict the **volume** of gas that will be produced at SATP when 20.0 mL of 6.00 mol/L nitric acid reacts with excess copper.
   a. 24.8 mL
   b. 30.0 mL
   c. 120 mL
   d. 744 mL

15. The experimental design that is suitable for determining the **mass** of a **precipitate** formed in a double replacement reaction is:
   a. Crystallization
   b. Filtration
   c. Gas collection
   d. Titration

Part II – Written Response

Show all your work. Read carefully.

1. In 1986, more than 154 billion kilograms of sulfuric acid were produced in North America, making it the most produced chemical. Sulfuric acid's uses range from fertilizers to explosives, to applications in pharmaceuticals and dyes. A titration was performed to completely neutralize a sample of 45.0 mL of sulfuric acid using 1.22 mol/L barium hydroxide. The **initial** buret reading was 1.2 mL and the **final** reading was 24.6 mL.

   Determine the molar concentration of the 45.0 mL sample of sulfuric acid.

2. Answer the **problem** of the following investigation report.

   Problem:
   What is the molar concentration of lead (ii) nitrate in the toxic waste solution?

   Experimental Design:
   A 10.0 mL sample of the toxic waste solution was reacted with an excess of sodium bromide in solution. The lead (ii) bromide precipitate was separated by filtration, dried, and its mass determined.

   Evidence:
   Mass of filter paper = 0.78 g
   Mass of filter paper and dried precipitate = 1.92 g

3. The first step in the production of nitric acid involves the conversion of ammonia to nitrogen monoxide. The **unbalanced** equation is as follows:

   $$\_\_\_\ NH_{3(g)} + \_\_\_\ O_{2(g)} \rightarrow \_\_\_\ NO_{(g)} + \_\_\_\ H_2O_{(l)}$$

   Calculate the number **moles** of oxygen that are required to completely react with 10.0 mol of ammonia.

4. A 30.0 mL sample of nitric acid was titrated with 1.75 mol/L potassium hydroxide. The volume of potassium hydroxide used for each trial was 8.4 mL, 8.6 mL, and 8.5 mL. Determine the concentration of the nitric acid.

5. Calculate the mass of solid product that would be expected to form during the reaction of 50.0 g of magnesium with 30.0 g of phosphorous.

APPENDIX O

STUDENT INTERVIEW QUESTIONS

Chemistry 20
Student Interview Questions

Instructions

The following questions were asked of the student subjects in the treatment group after the completion of the stoichiometry unit.

The following statements are to be read to the student subjects prior to commencing the interview:

Participation in this interview is voluntary and you can choose to not answer any question that you don't want to answer, and you can stop this interview at any time.

Your participation or non-participation will not affect your grade or your class standing in any way.

Questions

1. Do you enjoy chemistry? Why or why not?

2. Do you find chemistry to be a difficult subject? Why or why not?

3. What did you think about the Chemistry Skills Review Exam?

4. Do you enjoy laboratory work? Why or why not?

5. Did the performance assessments have an impact on your lab skills?

6. Did the performance assessments have an impact on your attitude toward lab work in chemistry?

7. What did you like about the performance assessments?

8. What did you not like about the performance assessments?

9. Would you like to have other performance assessments for other lab skills? Why or why not?

10. Do you think that the use of performance assessments has had an impact on your attitude toward chemistry more broadly?

11. Will you take future chemistry courses? If so, do you think that doing performance assessments has changed how you view your future in chemistry?

12. Did the use of the self-assessment checklist of your lab skills encourage you to think about your learning? In what ways?

13. Do you reflect over your own learning?

14. Do you think that you improved as a chemist because of the performance assessments?

15. Did the performance assessments affect the way that you understand stoichiometry?

16. Is there anything else that you would like to tell me about the use of laboratory skills performance assessments for learning