

PIPETTING AND GRAPHING AND CONVERSIONS, OH MY! MOTIVATIONAL
ASSESSMENTS THAT TEACH LAB SKILLS

by

Carol A. Teintze

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Carol Annette Teintze

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DEDICATION

I would like to dedicate this paper to my wonderful husband, Martin Teintze for his love, encouragement and support while I was pursuing my master's degree. I am also grateful for all his time and patience while helping me with the computer at various times during my on-line courses. I am grateful to Margaret Maben for getting me interested in the MSSE program in the first place and being my photographer. I am also grateful to John Graves for his guidance, instruction and inspiration which challenged me to improve the way I teach and helped me grow professionally. Many thanks also to Gwendy Stuart and the Chemistry & Biochemistry Department for giving me the opportunity to undertake this project.

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ABSTRACT

Developing lab skills is one of the purposes of the lab experience, yet students struggle with mastering them. Students are exposed to a number of common laboratory lab techniques, but they just don't get enough practice to master them. My primary goal was to design performance assessments to help students master some basic lab skills and see their relevance to their future classes and careers. A secondary goal was to design a tool that was easy for teaching assistants to use with a simple means of measuring outcomes. Five lab skills were targeted: pipetting, use of balances, metric conversions, graphing, creating standard curves, and data analysis using standard curves. By the end of the semester, 100% of students mastered pipetting and use of balances, 97% of students had mastered graphing standard curves and 100% could analyze data from a standard curve. Only 81% mastered metric conversions. Surveys and an interview showed students' awareness of the relevance of lab skills had increased and they found the performance assessments fun and motivating.

CONTRIBUTION OF AUTHORS AND CO-AUTHORS

Author: Carol A. Teintze

Contribution: Conceived the study, collected and analyzed the data, and wrote the manuscript.

Co-authors: John Graves and Kim Naegele

Contributions: Edited the manuscript at all stages.

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INTRODUCTION AND BACKGROUND

As an instructor of first-year biochemistry labs, I have often been frustrated by the number of students who receive perfect scores on their lab reports while their data reveals far from perfect lab skills. Laboratory courses at Montana State University (MSU) are designed to reinforce concepts that are taught in the lecture portion of the course. Students have the opportunity to experience wet labs where they are required to use basic lab skills to perform scientific experiments, but there is no mechanism in place to assess for skill development nor is there supervision or feedback given to students on their technique. The emphasis on acquiring conceptual knowledge has eclipsed the need to teach students basic manipulative lab skills that are common to most science courses and expected by employers in a wide variety of careers.

During the fall semester of 2011, I created a performance assessment using a laboratory skills check list which was placed at each work station to make students aware of the basic skills required for each task. As I observed their techniques, I rated the students' skill level and noted improvements they made as they worked through the assignment. They also rated themselves. Students were focused on their technique, and I gave them suggestions as needed. They assumed this checklist would be used as part of their lab grade since they were required to turn it in with their lab report. In fact, I just wanted to see what effect the performance assessment would have on their lab skills. It was surprising to discover how many students lacked basic skills I assumed they already had. I decided to find out how basic lab skills were assessed in the other labs in my department.

I narrowed the lab skills required for the techniques we teach down to five foundational skills: pipetting, use of balances, metric unit manipulations, graphing data,

and analyzing data using a standard curve. Then I conducted interviews of laboratory course instructors, lab coordinators, and research faculty who work with graduate and undergraduate students in the Chemistry & Biochemistry Department at MSU.

Surprisingly there is no assessment for these basic lab skills, even though students who become seniors are persistently weak in these areas. The freshman chemistry lab coordinator said students never learn proper pipetting technique because they are not held accountable for that. The problem our department has is that in large lecture courses there is not enough funding available to provide adequate teaching assistant (TA) training to teach lab skills and not enough manpower to provide TA oversight. The lab instructor for the 400-level course for biochemistry majors said, "I assume they (students) have competent basic lab skills when they come in here. They should have learned these skills in freshman chemistry." However he was dismayed that many of his students lacked the basic lab skills essential for his course. What they told me not only validated the need for this study but led me to ask the question: Can performance assessments be used to teach mastery of basic lab skills?

CONCEPTUAL FRAMEWORK

Employers today are demanding employees with more effective problem solving skills, analytical skills, interpersonal skills, and manipulative laboratory skills. Yet many students entering the workforce are not adequately prepared to meet these demands (Allen, 2000). Faculty members are finding that while computer-based labs have practical and educational purpose, they have replaced some of the traditional wet labs. This has affected the skill level of students going into research-based graduate programs and professional careers because they have fewer opportunities to master basic laboratory skills (Handelsman,

Miller, & Pfund, 2007; Moni, Hryciw, Poronnik, Lluca, & Moni, 2007). Instructors see their undergraduate classrooms filled with students who seem to be more concerned about getting an “A” grade than learning concepts and mastering skills (Diegelman-Parente, 2011).

Since the National Science Education Standards were published in 1997, numerous reports and papers have been published recommending that colleges change their curriculums to better reflect the science done in the 21st Century. There were specific recommendations given in relation to undergraduate laboratory work:

- a. Undergraduate students should have opportunities to engage in authentic scientific research so they can learn how to solve complex problems and not just memorize facts.
- b. They should understand the interdisciplinary nature of science and be able to communicate and collaborate with others.
- c. Students should be able to generate a question and develop a hypothesis to investigate.
- d. They should be able to quantitatively interpret and analyze data, identify inconsistencies and draw reasonable conclusions.
- e. They should be able to perform accurate measurements and make solutions of a given concentration.
- f. They should have experience with computational systems using large data bases (American Chemical Society Committee on Professional Training, 2008; Grunwald & Hartman, 2010; Heady, 2000; National Academy of Sciences, 2000; National Research Council, 2003; Woodin, & Fletcher, 2010).

Laboratory courses for undergraduates are designed to engage students in the practice of doing science and to give them hands-on experience with current laboratory equipment. Objectives for each laboratory exercise integrate conceptual learning with exposure to laboratory techniques. It is the ideal setting for students to experience authentic science, learn problem solving skills, master basic laboratory skills, and learn to work in teams (Doran, Chan, Tamir, & Lenhardt, 2002). Mastery of these skills is developed by learning component skills and practicing them numerous times. While most laboratory courses require that students measure and weigh chemicals accurately, make proper dilutions, and use technical equipment, there is no direct supervision or assessment provided to give them the feedback they need to help them develop good techniques and for them to see their improvement (Moni et al., 2007). Well-designed lab skill assessments incorporated into experiments can be used as feedback for the student and instructor as a measure of progress in skill development and learning. They provide useful information to the student to improve performance and useful information to the instructor to improve their teaching (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010; Angelo & Cross, 1993; Black, Harrison, Lee, Marshall, & Wiliam 2004; Guskey, 2003; Heady, 2000).

Assessments designed with the dual purpose of providing feedback to students themselves for their learning and to teachers to modify their instruction are called formative assessments. When goals are specific and feedback is focused, they are mutually beneficial to the teacher and student (Angelo & Cross, 1993). A study by Black and Wiliam showed assessment feedback raises achievement and increases learning. “When anyone is trying to learn, feedback about the effort has three elements: recognition of the desired goal, evidence about the present position, and some understanding of a way to close the gap between the

two” (Black & Wiliam, 1998, p 143). They showed formative assessments can be even more effective when they are linked to student self-assessments. As students learn how to assess themselves, they are motivated to become actively involved with their learning.

Checklists are a useful assessment format for performance-based tasks. Manipulative lab skills and laboratory techniques can be reinforced and the management of data can be kept simple. A checklist assessment form used during lab activities could be kept in each student’s file where lab skills are assessed for formative purposes and students receive feedback on their skill achievement. A summative evaluation can then be used at the end of the assessment period to certify a student’s demonstration of a set of skills upon completion of the course (Doran et al., 2002; Ludwig, Bentz, & Fyneweever, 2011; Wiggins, 1998).

Students’ motivation to develop scientific reasoning and manipulative skills is influenced by the value they place on what they are learning. Value is increased when students are provided with real world tasks that are relevant to their future classes and professions. Formative assessments can potentially motivate students to see the value of the marketable skills they are developing, give them confidence and support the underlying concepts they are learning. Students can follow their progress and take ownership of their learning and skill development. The design of formative assessments plays an important role in student motivation. Formative assessments that give positive feedback and inform the student how to improve the quality of their work is essential (Ambrose et al., 2010; McKenna, 2011; Moni et al., 2007; Weld, Stier, & McNew-Birren, 2011).

Performance-based assessments and formative assessments improve achievement, student confidence, student motivation, communication, science reasoning skills and manipulative skills. Laboratory-based performance assessments provide a comprehensive

tool that encompasses both inquiry cognitive skills and manipulative skills that are relevant and marketable (Black & Wiliam, 1998; Black et al., 2004; Grunwald & Hartman, 2010; Moni et al., 2007; Newcomb, 2009; Steen, 2011).

METHODOLOGY

For the purpose of this study, I targeted five essential lab skills that are routinely used in our introductory chemistry and biochemistry courses that students have difficulty mastering. These skills are pipetting, the use of balances, metric conversions, graphing, and analyzing data using a standard curve. In order to reach mastery of manipulative lab skills, much repetition is required. Properly designed performance assessments could solve this problem. The primary treatment goal of this project was to address the question: Can performance assessments be used to teach mastery of laboratory skills and provide motivational feedback? Secondary questions were: Do students feel lab skills are relevant to their future classes and careers? Does a student's major affect their motivation to learn lab skills?

Introduction to Chemistry and Biochemistry is a required course for non-majors that has both lecture and laboratory components. Students majoring in Nursing, Fish and Wildlife Management, Animal Science, and Range Ecology are the most common in this class. The lab sessions are three hours long and meet once a week. There are approximately 17 students in each lab section, and I conducted this study on 2 lab sections ($N = 34$). 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.

At the beginning of the semester I gave my students the Lab Experience Survey (Appendix A). Students reported their major, evaluated how much experience they had using different types of pipettes, how much graphing they had done and how relevant these skills were to them for future courses and careers. The data were processed using a five-point Likert scale where one was no experience and five was very experienced. I reported the results back to the students and explained how I was going to focus on helping them develop marketable lab skills.

My first treatment method taught basic graphing, how to create a standard curve and data analysis using a standard curve. Students were required to create standard curves as part of three separate lab exercises. During each of these labs, students had three graphing exercises: a practice graphing exercise was demonstrated, a graphing worksheet was given as a quiz, and then students graphed and analyzed their experimental results. Students learned how to determine the scale for their axes, how to plot points, how to determine where to place their best fit line and how to use the standard curve to analyze data and determine the value of an unknown. Graphs were assessed using the rubrics indicated for the appropriate exercise and each student's progress for the three graphing exercises was monitored on their Lab Skill Training: Graphing and Standard Curves assessment sheet (Appendix B). Students were given feedback on their graphs the following week.

The first graphing exercise was employed during a lab which required performing a colorimetric assay using a spectrophotometer. Students performed this assay on a series of stock glucose standards with known concentrations. They created a standard curve by graphing the absorbance (y) as a function of the concentration (x) and drawing a best fit

straight line through the points generated by the standard dilutions. Students were assigned two samples of unknown glucose concentration and were asked to determine their concentrations using their standard curve.

Before starting the experiment, I provided the students with quad ruled graph paper and the Graphing Exercise #1 Practice Worksheet (Appendix C). I demonstrated how to set up the axes of the graph and how to plot the points of the data on the white board. Together we created a standard curve using the practice worksheet. Then I gave them the absorbance values of two unknowns and as a group we determined the concentrations of the unknowns. We talked about other applications of standard curves used in completely different contexts to increase students' awareness of their relevance in a variety of settings. Next, I gave the students the Graphing Exercise #1 Quiz Worksheet (Appendix C). They had to create a graph, plot the points, create a standard curve and determine the concentration of an unknown when given the absorbance value. Then, the students performed the glucose assay lab and applied the graphing skill to their own experimental data. The two graphs were graded using the Dilutions Graphing Rubric (Appendix D) and the scores were recorded on the Lab Skill Training: Graphing assessment sheets. After returning their lab reports the following week, I gave the students the Graphing Post-Survey (Appendix E) and compared their perceived graphing skill development and attitude towards graphing with their responses to the Lab Experience Survey.

Several weeks later, the DNA electrophoresis experiment provided the second opportunity to create a standard curve by plotting the distance the DNA fragments traveled (x) against the base pair size of the known DNA fragments (y) from a *Hind* III

cut of λ phage DNA standard. The distance a DNA fragment migrates on a gel is a function of the log of its size. Therefore the data were graphed on semi-logarithmic paper to obtain a straight line. It is a more difficult concept to grasp. Three samples containing whole plasmid, cut plasmid and *Hind* III standard were loaded in separate lanes on students' gels. While the gels were running, I drew a picture of this type of gel with the typical band patterns of the DNA on the white board. I demonstrated how to create a standard curve using a semi-logarithmic scale and how to determine the size of unknown DNA fragments based on the distance they traveled in a gel. When they felt they understood the concept, students were each given the Graphing Exercise #2: DNA Graphing Worksheet as a quiz (Appendix F). They were asked to create a standard curve using the *Hind* III standard and determine the sizes of the plasmid and cut plasmid DNA fragments. After the gels were run, the fluorescing bands were observed on a UV light box and the gels were photographed. After repeating the graphing exercise with the photographs of their own gels, students compared the results from their graphs with the DNA Graphing Worksheet quiz. Although the photographs came from different gels and the distances migrated were therefore not the same, the sizes of the DNA fragments obtained from the graphs should have been the same. Both graphs were assessed using the DNA Graphing Rubric (Appendix G) and each student's progress was recorded on their graphing performance assessment sheet.

The third opportunity to graph data and create a standard curve was again a DNA gel electrophoresis lab, but this time students isolated their own genomic DNA and amplified a region containing a polymorphic repeat by PCR to create their own personal DNA fingerprint. Following the genomic isolation, I demonstrated how to create a

logarithmic standard curve using a 100 base pair (bp) ladder DNA standard. Students were given the Graphing Exercise #3: Fingerprint Graphing Worksheet and asked to determine the sizes of the DNA fragments in one of the lanes (Appendix H). For the quiz, they were asked to determine the sizes of the fragments from a different lane using the same curve. The next week, each student's DNA was loaded on a gel with the 100 bp DNA standard. While the gels were running, students worked through a graphing problem in the lab manual just like the one from the week before. When the gels had run long enough, they were placed on a UV light box and photographed. Using the photograph, students created a standard curve from the DNA standard and determined the sizes of their own DNA fragments. The DNA Graphing Rubric was used again on their graphs and their scores were recorded on their graphing performance assessment sheet. By calculating the number of polymorphic repeats contained within their DNA fragments and comparing them to a frequency chart, students took the analysis of the sizes of their DNA fragments a step further to determine if they had rare or common alleles.

The Lab Skill Training: Graphing and Standard Curves performance assessment sheet was used to determine overall student graphing skill progress two ways: by evidence of improvement within each lab period and by comparing the scores of the three graphing exercises over the course of the semester. The level of difficulty of the graphing problem was also taken into consideration.

For the second treatment I developed the Lab Skill Training: Pipette Use and Metric Conversions performance assessment tool to teach students how to properly use a micropipette, to measure the accuracy of their technique using both a regular balance and an analytical balance, and then to convert the units from microliters (μl) to milliliters

(ml), and from grams (g) to milligrams (mg) (Appendix I). Students tracked their own skill development while performing repeated trials with their lab partner. A rubric to assess for correct conversions, attempts at accuracy, mastery and completeness was included on the performance assessment and counted toward one third of the lab report grade, or the equivalent of the weekly quiz. In order to use this performance assessment tool, I needed to identify a lab exercise where we had a 30 minute pause between steps in an experiment and where we were using the micropipettes and balances repeatedly. We were preparing agarose gels for DNA electrophoresis and during the time needed for the gels to solidify, students used the Lab Skill Training: Pipetting and Metric Conversions performance assessment tool to teach themselves these three skills.

Three sizes of micropipettes were provided for each set of two students: the p1000 which measures up to 1000 μ l, the p200 which measures up to 200 μ l and the p20 which measures up to 20 μ l. Students followed the directions for using the p1000 first, setting the dial to the volume required on the chart, and drawing water up into the pipette tip. For each volume setting the students recorded the weight of the water expelled into a weigh dish on the balance. Students repeated each measurement three times until they were able to deliver the correct amount.

At the same time, students taught themselves and each other how to use the balances. The balances had to be zeroed after a weigh boat was placed on it. When they started measuring with the p200, they discovered the normal balances used in class were not designed to measure such small amounts, and they had to decide at what point to use the analytical balances. Then they found out doors on the analytical balances had to be

shut when being used because the slightest breeze from a passerby caused the scale to fluctuate.

For the metric conversion portion of the performance assessment, students were asked to make metric conversions from μl to ml for the volume settings on the micropipettes in the starred columns. Then, since the balances weighed the volumes in g, they converted those values to mg in the last starred column.

The rubric printed directly on the Lab Skill Training: Pipetting and Metric Conversions assessment sheet was used for grading purposes and was scored like a quiz. Mastery for pipetting was determined if measurements were within 0.02g for the p1000 and the p200, and within 0.001g for the p20. Mastery of metric conversions was awarded when all conversion values were correct.

At the end of the semester, I randomly interviewed 11 students either as they were finishing up their lab reports or during office hours ($n = 11$). They were all asked the same questions from Interview Questions for Students and represented different majors and different academic levels (Appendix J). The interview allowed me to determine if students felt the lab skill training exercises were beneficial, motivational and effective. Their responses were also compared to the Lab Experience Survey. Table 1 shows the various sources of my data from this study.

Table 1
Data Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3	Data source 4
<i>Primary Question:</i>				
1. Can performance assessments teach lab skills and give motivational feedback?	Performance assessment	Quizzes and lab reports	Interview survey	Post-
2. Do students feel lab skills are relevant to their future classes and careers?	Survey	Interview	Performance assessment	
3. Does a student's major affect their motivation to learn lab skills?	Survey	Interview	Performance assessment	Quizzes, lab report

DATA ANALYSIS

Findings from the Lab Experience Survey showed 31% of students felt lab skills were *very relevant* to their careers, 31% said they were *fairly relevant*, 22% said they were *somewhat relevant*, and 16% felt they had *very little relevance* ($N = 33$). Among nursing students 39% said lab skills were *very relevant* and 36% said lab skills were *fairly relevant* ($n = 25$). One nursing student said, "I think basic metric system knowledge and graphing technique will benefit me most throughout this class as well as my future career because most measurements used in the medical field refer to the metric system." In contrast, none of the animal science and fish and wildlife (FWP) majors found lab skills to be *very relevant* and 40% felt they had *very little relevance* ($n = 8$). One student wrote, "These skills are not relevant to my career. I will be working on a ranch" (Figure 1).

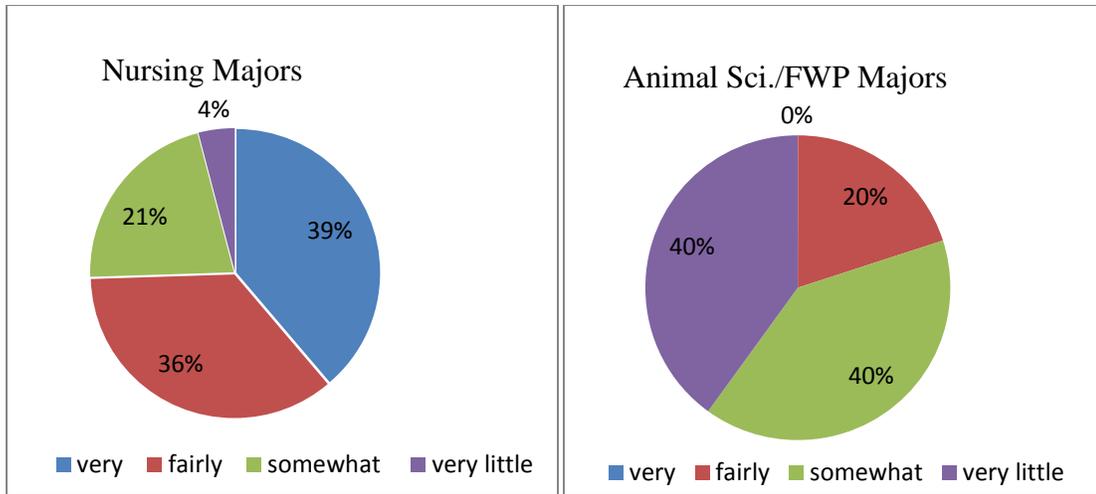
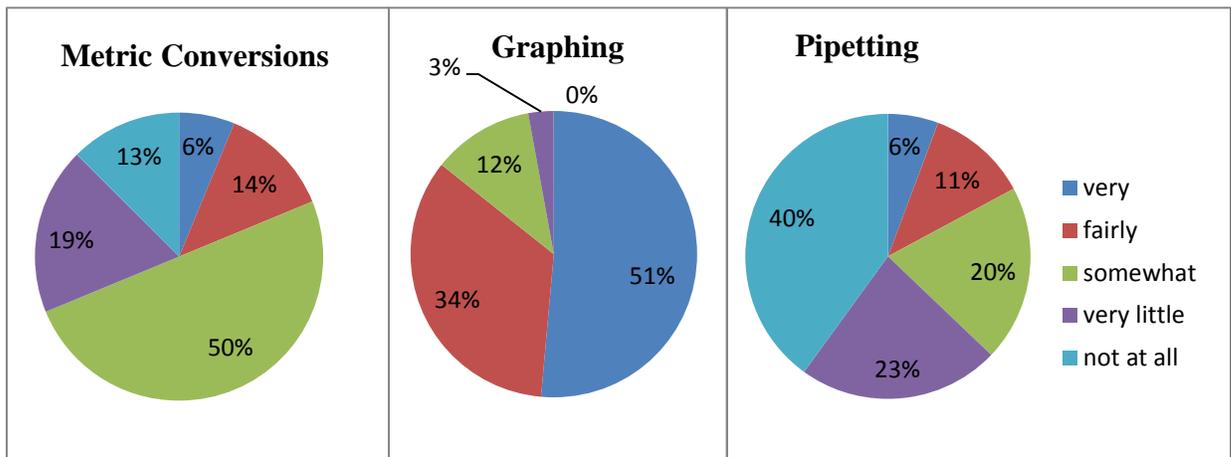


Figure 1. Survey of attitude towards relevance of lab skills to future careers by nursing majors, (n = 25), and animal science & fish and wildlife majors, (n = 5).

From the three lab skills surveyed for amount of experience (graphing, metric conversions and pipetting), 86% of students were either *very skilled* or *fairly skilled* with creating and reading graphs. On the other hand only 18% of students were either *very confident* or *fairly confident* with ml to μ l metric conversions and only 17% were *very* or *fairly experienced* with using a micropipette. Forty percent of students had never used a micropipette (Figure 2).



When asked what lab skills were most relevant to them, more than half of the students said graphing and metric conversions were the most relevant. An animal science majors said, “Being able to create and read graphs will be most important for my future classes and career. I will be making lots of graphs.” One student said, “I think measuring accurately and converting units are the most relevant for me as a nursing major, since I will be administering medication which may not be in the right measurement.” Only 27% said pipetting was relevant.

Results from the first graphing exercise after the demonstration and the practice problem showed 81% of students had mastered the ability to create a standard curve from their experimental data and 84% of students were able to determine the values of the two unknowns from the standard curves they had drawn ($N = 30$). One student said, “It was helpful to practice twice before graphing our results from the experiment. It has been a long time.” When surveyed after the first graphing exercise, 57% of students said their ability to draw standard curves had increased, and out of those, 18% said their ability increased two-fold. One student wrote, “I feel better about making graphs!” Fifty-seven percent said their perception of the relevance of graphing to their careers had changed. One student made the comment, “Graphing has universal applications. It’s relevant even if I change my major.”

The second graphing exercise showed 100% of students mastered the ability to create a logarithmic standard curve after the demonstration ($N = 32$) (Figure 3). On the practice quiz, only 25% were able to determine all three unknowns from their standard curve and only 56% were able to determine all three unknowns on the lab report. The most common error was misreading the unknown that fell on the lowest end of the log

graph where there were twice as many divisions on the graph paper than for the other regions of the graph (Figure 4).

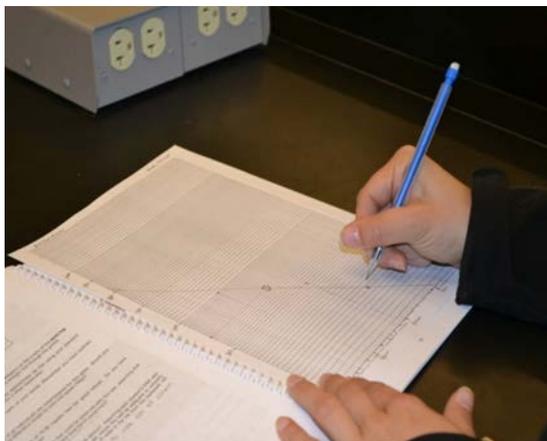


Figure 3. Graphing a logarithmic standard curve.



Figure 4. Using standard curves to analyze data.

When given the DNA fingerprint graphing quiz from the third graphing exercise, 22% of students ($N = 31$) either plotted points incorrectly or chose the wrong points when placing the line for the standard curve. Nineteen percent had these similar graphing mistakes on the graphing problem contained in the lab manual. Results from graphing their own DNA fingerprint showed only one student made graphing errors. She had not made graphing errors on the previous two graphing problems, but had set up the logarithmic axis incorrectly on the last graph. This shows 97% of students mastered creating standard curves and analysis of data using their standard curve without assistance. Several students I interviewed at the conclusion of the lab skill training period said the graphing exercises were the most beneficial. One nursing student said, “Definitely graphing benefited me the most. It was a foreign language to me before.”

I asked the other TAs how their students did with their standard curves by the end of the semester. One said, “About 10% knew how to draw standard curves and determine their unknowns unassisted, another 15% could do it with help, and 75% were clueless.”

Another said, “They did have problems figuring out which axis was which so I put that on the board for them. Most had to redo it (the line) because it didn’t get thru all the points. About one third to one half were able to get a nice fit curve, but one quarter were still drawing dot-to-dot (instead of a straight line).



Figure 5. Adjusting the micropipette.

Results from the pipetting assessment showed 41% of students mastered pipetting with the first trial and 100% reached mastery trials ($N = 32$). One student commented, “This was a good lab. You should keep doing this. I took Micro and they just expected you to be

able to do this (pipetting) already.” For the experiment, students were instructed to load 5 μ l of each sample onto their gels. Using the p20’s, 100% of students successfully loaded the correct volumes on their gels which was confirmed when the gels were viewed on the UV light boxes. When interviewed, several students said the pipetting performance assessment was fun and the competition was motivational. One student said, “I wanted to prove to the people around me that I could get it right every time. The friendly competition really motivated me and I think students like competition.” Another student said, “It was fun just to see my progress.” Other students said the pipetting performance assessment benefitted them the most because they had never used a micropipette before and did not realize how mistakes with such small measurements could affect their data.

With metric conversions, 78% mastered all the metric conversions, 13% left them blank and 9% needed improvement. From the 9%, two students made incorrect volume

conversions and one student made incorrect weight conversions. Those students who left them blank said they overlooked the metric conversions and were given the opportunity to do them. This increased the amount of students who reached mastery to 81%. Several students interviewed felt there could have been more practice doing metric conversions. One student said doing the metric conversions together with the pipetting, “put how much these quantities were into perspective.”

INTERPRETATION AND CONCLUSIONS

This study revealed that performance assessments that provide students with lots of repetition are very effective tools for teaching basic lab skills. Even though the majority of students had little or no experience using micropipettes, and even though most students did not even feel pipetting was a relevant skill, all mastered accurate pipetting using Lab

Skill Training: Pipetting and Metric

Conversions. Students had so much fun with the self-assessment, they were giving each other high fives or doing fist pumps (Figure 6). It was very motivating. Students enjoyed showing each other how proficient they were



Figure 6. High five.

pipetting and they enjoyed seeing their own improvement. They mastered three skills: pipetting, use of balances and metric conversions. The student's major was not a factor.

Even more impressive was how many students mastered the ability to graph data, create standard curves and correctly analyze data compared to the other lab sections. It was difficult to tell if self-assessment was a motivating factor on the graphing exercise. Due to the time needed to score the graphing exercises, students did not see them until

the next week. The repetitive exercises seemed to be the greatest factor in mastering the graphing exercises. Again, it did not seem to matter what the students' majors were.

In the future I would include more metric conversion practice problems. The performance assessment was weak in this area. I would also develop more challenging exercises to use the balances for.

Developing lab skills is one of the purposes of the lab experience, and the benefits of lab skill training to students for their future classes and careers are substantial. I was overwhelmed by how much students appreciated the lab skill training. They kept coming to me at the end of the semester and thanking me. Students often come to lab unaware of the relevance these skills have out in the real world and therefore don't place value on learning them. An additional outcome of this treatment was it increased students' awareness of their relevance, gave them a sense of accomplishment that they developed some marketable skills and it increased their confidence in their ability to perform these skills well.

In large lecture classes where TA instruction and oversight is minimal, these tools could be easily implemented without the need for additional TA training. These assessments were fun and motivational for all majors. Considering each assessment training exercise taught three lab skills, they worked quite well. They can be modified for training with different types of pipettes and a wide variety of graphs. In the future, I would include a focus for the graphing exercises on how to set up the axes and how to determine the appropriate scale.

VALUE

I have experienced a shift in my awareness of students as learners as a result of participating in this study, and this has changed the way I teach. Because of the dramatic

results, I have a greater trust in students that they really want to learn and they are not just interested in a good grade. I had more of my own students and students from other sections coming to my office hours on a regular basis.

There are ways to develop assessments that motivate, engage and encourage students; assessments that give them permission to make imperfect progress and are affirming. I have become aware of ways that I might help students learn. It has opened up opportunities for conversations about how students learn with my colleagues so that the Lab Skill Training: Pipetting and Metric Conversions assessment will be implemented by other instructors this summer. We will see how an untrained TA is able to use it.

The assessments from this study may serve as a model for teaching other skills, but for me they served as an example of how I can implement other structures into our labs to increase student learning. If students are not learning, it may be that my teaching methods need to change. I also need to keep changing the way I teach because the students of each new generation may learn differently from the previous one. When I reflect back on how a lab went, now I look for ways to improve it, taking advantage of the information available from the experiences of other instructors on the internet and learning how to use new technologies.

Becoming a student again made me remember what it was like to be a novice and I saw how confusing it is to learn a new lab skill when you don't know what you are doing or why. It made me much more sympathetic to my students. I will continue to take classes and attend workshops to further my professional growth and promote interactions with my colleagues.

REFERENCES

- Allen, L. (2000). *Competencies That Count: Strategies for assessing high-performance skills. LAB Working Paper No. 2.* Northeast and Islands Regional Educational Lab at Brown University, Providence, RI.
- American Chemical Society (ACS) Committee on Professional Training. (2008). *Undergraduate Professional Education in Chemistry: ACS Guidelines and Evaluation Procedures for Bachelor's Degree Programs.* Washington, D.C.
- Ambrose, S.A., Bridges, M.W., DiPietro, M., Lovett, M.C., Norman, M.K. (2010). *How Learning Works: Seven research-based principles for smart teaching.* San Francisco: Jossey-Bass.
- Angelo, T.A. and Cross, K.P. (1993). *Classroom assessment techniques: A handbook for college teachers.* San Francisco: Jossey-Bass.
- Black, P. and Wiliam, D. (1998). Inside the black box: Raising standards through classroom assessment. *Phi Delta Kappan* 80(2):139-148.
- Black, P., Harrison, C., Lee, C., Marshall, B., Wiliam, D. (2004). Working inside the black box: assessment for learning in the classroom. *Phi Delta Kappan* 86(1): 8-21.
- Diegelman-Parente, A.(2011). The use of mastery learning with competency based grading in an organic chemistry course. *Journal of College Science Teaching* 40, (5) 50-58
- Doran, R., Chan, F., Tamir, P., Lenhardt, C. (2002). *Science Educator's Guide to Laboratory Assessment.* NSTA Press
- Guskey, T.R. (2003). How classroom assessments improve learning. *Educational Leadership*, 60, (5): 6-11
- Grunwald, S. and Hartman, A. (2010). A case-based approach improves science students' experimental variable identification skills. *Journal of College Science Teaching.* January/February 28-33
- Heady, J.E. (2000). Assessment-a way of thinking about learning-now and in the future: the dynamic and ongoing nature of measuring and improving student learning. *Journal of College Science Teaching.* May 2000: 415-421
- Handelsman, J., Miller, S., Pfund, C. (2007). *Scientific Teaching.* The Wisconsin Program for Scientific Teaching. New York: W.H. Freeman and Company

- Ludwig, M.A., Bentz, A.E., Fynewever, H. (2011). Your syllabus should set the stage for assessment learning. *Journal of College Science Teaching* 40, (4): 20-23
- McKenna, E.S., (2011). *Student use of formative assessments and progress charts of formative assessments in the 7th grade science class*. Unpublished professional paper, Montana State University-Bozeman.
- Moni, R.W., Hryciw, D.H., Poronnik, P., Lluka, L.J., Moni, K.B. (2007) Assessing core manipulative skills in a large, first-year laboratory. *Advances in Physiological Education* 31, 266-269.
- National Academy of Sciences. (2000). *Introducing the National Science Education Standards*, Booklet 1997. National Academy Press
- National Research Council.(2003). *Bio2010: Transforming undergraduate education for future biologists. Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century*, Board on Life Sciences, Division on Earth and Life Studies, Washington D.C.: National Academy Press
- Newcomb, R., (2009). *Strategies to improve internal assessment scores in IB experimental science*. Unpublished professional paper, Montana State University
- Steen, M., (2011) *Investigating the impact of a laboratory skills checklist on student engagement in biology*. Unpublished professional paper, Montana State University-Bozeman
- Weld, J., Stier, M., McNew-Birren, J. (2011) The development of a novel measure of scientific reasoning growth among college freshmen: The constructive inquiry science reasoning skills test. *Journal of College Science Teaching* 40, (4): 101-107
- Woodin, T., Carter, V.C., Fletcher, L. (2010). Vision and change in biology undergraduate education, a call for action-initial responses. Feature from the National Science Foundation. *CBE-Life Sciences Education* Vol. 9, 71-73.
- Wiggins, G. (1998). *“Individual Performance Tasks” in Educative Assessment*. San Francisco: Jossey-Bass pp. 139-152.

APPENDICES

APPENDIX A

LAB EXPERIENCE SURVEY

Lab Experience Survey

Name _____ Major _____

Your answers to this survey will have no effect on your grade. The data will be used for research purposes. I do not wish my data from this survey be used _____

Please use the following 1-5 rating scale to answer the questions below:

1 Not at all, 2 Very little, 3 Somewhat, 4 Good, 5 Very

1. How familiar are you with the metric system of measurement? 1 2 3 4 5
2. How confident are you with converting metric units from g to mg? 1 2 3 4 5
3. How often have you used a serological pipette? 1 2 3 4 5
4. Have you ever used a micropipette? 1 2 3 4 5
5. Have you converted units from milliliters to microliters? 1 2 3 4 5
6. Have you ever used an analytical balance? 1 2 3 4 5
7. Have you calculated concentrations from dilutions you made? 1 2 3 4 5
8. How confident are you with recording data on a graph? 1 2 3 4 5
9. How skilled are you with reading information from a graph? 1 2 3 4 5
10. How relevant are these skills to you for your future classes? 1 2 3 4 5
11. How relevant are these skills to you for your future career? 1 2 3 4 5

Which skills mentioned are the most/or least relevant to you as non-career related life skills. Why?

Are there additional basic lab skills that would also be relevant to you?

APPENDIX B

LAB SKILL TRAINING: GRAPHING AND STANDARD CURVES

LAB SKILL TRAINING: Graphing and Standard Curve

Name _____

Lab Exercise	Axis set up	Plotting points	Line placement	Unknown Determined	Score
Glucose Lab					
1. Demo Graph					
2. Practice Problem					
3. Lab Data Graph					
DNA Lab					
1. Demo Graph					
2. Practice Problem					
3. Lab Data Graph					
PCR Lab					
1. Demo Graph					
2. Practice Problem					
3. Lab Data Graph					

APPENDIX C

GRAPHING EXERCISE #1 PRACTICE STANDARD CURVE

Graphing Exercise #1: Practice Standard Curve

Data Table of Dilutions from a stock solution of 5mg/ml bovine

Test tube number Concentration (C_2) mg/ml Absorbance (560nm)

10 mg/ml 0.00

21 mg/ml 0.12

32 mg/ml 0.24

43 mg/ml 0.36

54 mg/ml 0.48

65 mg/ml 0.60

Create a graph on graph paper with Concentration on the X axis and Absorbance on the Y axis. Plot the data from the table above. Draw a best-fit straight line through the points using a ruler to create a standard curve.

If you have unknowns with absorbance values of 0.18 and 3.0, what would their respective protein concentrations be? Use the standard curve to determine the protein concentration.

APPENDIX D

GRAPHING EXERCISE #1 QUIZ

QUIZ Graphing Exercise #1

Name _____

Data Table

Standard Sample No. Absorbance Concentration of glucose mg/100ml

10.000.0

20.102.0

30.204.0

40.408.0

50.8016.0

Plot data for the standard samples on the graph below. Draw a straight line using the dots that you plotted. (You just created a standard curve) 2 pts.

If your unknown sample "B" gave you an absorbance of 0.60nm, what would the glucose concentration be?(1 pt)

If unknown sample "P" gave you an absorbance of 0.22nm, what would your concentration be?(1pt)

In humans the normal blood glucose level is in the 70-110 mg/100ml range. If your blood glucose level is above the 70-110 mg/100ml range, what kind of problem might this indicate?

APPENDIX E

DILUTIONS GRAPHING RUBRIC

DILUTIONS STANDARD CURVE RUBRIC (5pts)Name_____

Graphing:

- Axis: Set up x and y axis to reflect range of values, consistently spaced and labeled (1pt).
- Plotting points: points from standard placed correctly and accurately (1pt).

Standard Curve:

- Placement: line drawn through zero and an average of data points (1/2 pt).
- Straight line, not dot to dot or curved (1/2 pt).

Data Analysis

- Determined value of unknown using standard curve (1pt. each)

APPENDIX F

GRAPHING POST SURVEY

POST SURVEY: Affect of Graphing Exercise on lab skill

Name _____

Rate from 1-5 your perception of this graphing exercise in terms of relevance and lab skill development. 1 is not at all or much less, 2 less, 3 is medium or the same, 4 more, 5 is very or much more

Ability to set up the axis before this exercise? 1 2 3 4 5

Ability to set up the axis after this exercise? 1 2 3 4 5

Ability to plot points before this exercise? 1 2 3 4 5

Ability to plot points after this exercise? 1 2 3 4 5

Ability to draw a standard curve before? 1 2 3 4 5

Ability to draw a standard curve after? 1 2 3 4 5

Knew to draw a straight line, not dot-to-dot before? 1 2 3 4 5

Knew to draw a straight line after? 1 2 3 4 5

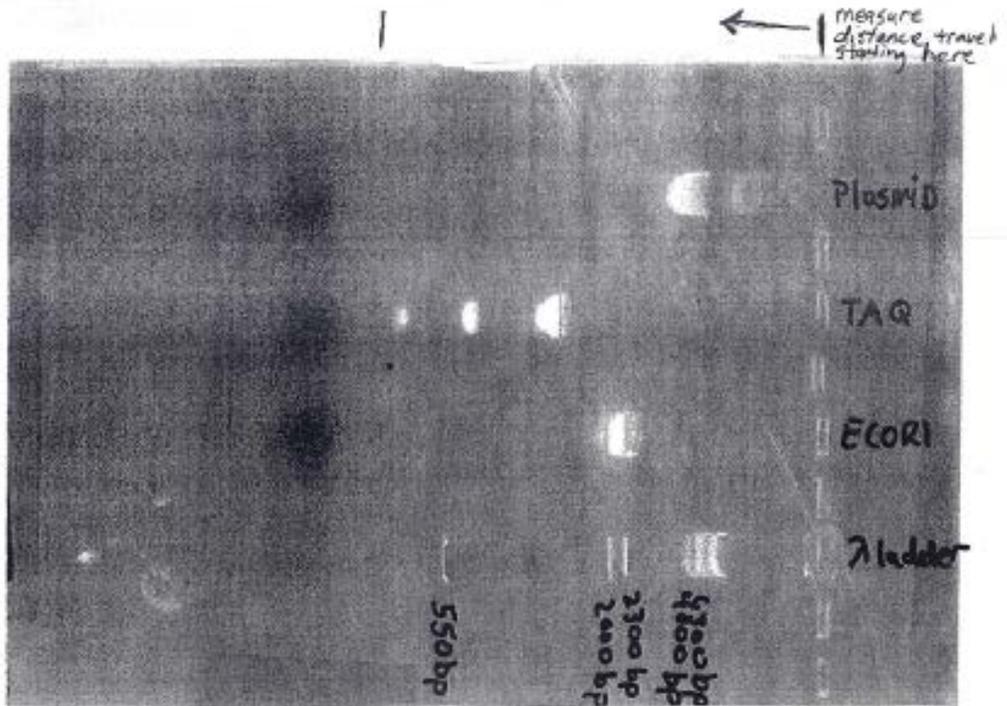
Ability to determine an unknown from a standard curve before? 1 2 3 4 5

Ability to determine an unknown from a standard curve after? 1 2 3 4 5

Has your perception of the relevance of this lab skill changed as a result of this exercise?
Y/N

APPENDIX G

GRAPHING EXERCISE #2



Using a ruler measure the distance travel in millimeters (mm) of DNA fragments in each well

Fill in data table

DNA ladder bp bp	Distance traveled(mm)
6300	
4000	
2300	
2000	
550	

DNA samples run in a logarithmic fashion rather than a linear fashion. Using the information in the table above create a standard curve using **semi-log graph paper**. Put the distance traveled on the X axis and your base pairs (bps) numbers on the Y axis. Make a best fit curve. (This should be a straight line.)

Record the distance traveled of plasmid data in the table below. Using your standard curve created by your DNA ladder figure out the base pair (bp) sizes of your DNA fragments. Use the distance traveled read up to the best fit line and read the Y axis. Fill in your DNA (plasmid) bp chart above.

Well#	Distance traveled (mm)	DNA bp (plasmid)
Plasmid		
TAQ-1		
-2		
-3		
Ecor I		

APPENDIX H

DNA GRAPHING RUBRIC

DNA Graphing Rubric (5 pts)

Name _____

GRAPHING:

Plotting points from the DNA ladder:

- Plasmid Gel: 550bp, 2000bp, 2300bp sized fragments (½ pt. each)
- Fingerprint Gel
 - 3 fragments from standard closest to student's fragments (½ pt each)
 - Axis: set up to reflect range of values (1 pt)

STANDARD CURVE:

Line placement (½ pt.): straight line, averaged line through points.

DATA ANALYSIS:

Plasmid Gel: Determination of bp size of the three TAQ cut DNA fragments (3 pts.)

Fingerprint Gel: Determination of bp size of student's own DNA fragments (2 pts.)

APPENDIX I

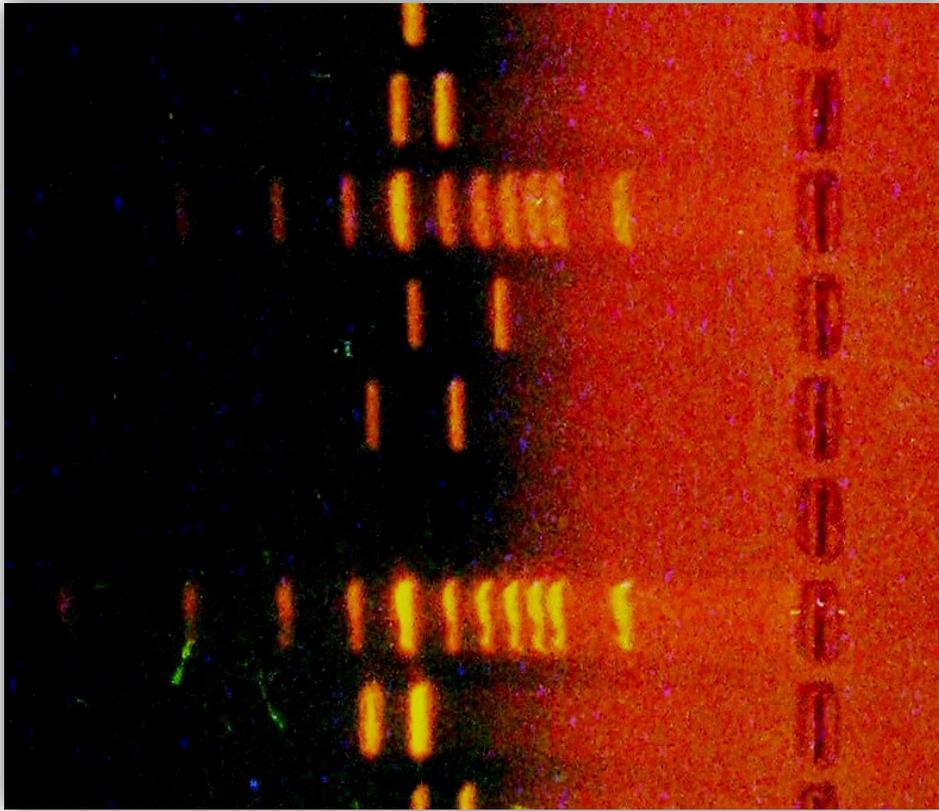
GRAPHING EXERCISE #3

DNA Fingerprint Graphing Worksheet

Name _____

This is a photograph contains a DNA 100 base pair ladder in lanes #3 and #7, counting from the top of the picture. The wells are on the right (negative pole) and samples ran to the left (positive pole). The size of the first band to the left of the well is 1500 bp, then 1000 bp, 900 bp, 800 bp, 700 bp, 600 bp, etc. The most prominent band in the ladder is the 500 bp fragment. The DNA fingerprint samples from different students have only two bands or DNA fragments.

1. Using the ladder in lane #3, measure the distance the 500bp, 600bp, and 700bp bands traveled and create a standard curve on semi-log paper. Record your measurements in a data table.
2. Determine the sizes of the two DNA fragments in lane #4. Circle their location on your standard curve. Record the distances the bands traveled and the sizes you determined in your data table.



APPENDIX J

LAB SKILL TRAINING: PIPETTE USE AND METRIC CONVERSIONS

LAB SKILL TRAINING: Pipetting and Metric Conversions NAME _____

A. Use the 1000 μ l micropipette (blue cap). Always hold it with the tip down.

1. Set the dial on the pipette to deliver the desired volume.

2. Put on a blue pipette tip.

3. Place the tip of the pipette into your beaker of water.

4. Push down the plunger till you reach the first stop. Slowly release to draw water up into the pipette tip. **DO NOT INVERT THE PIPETMAN.**

5. Expel the water onto the parafilm on the scale by pushing the plunger all the way down.

6. Record the weight. Repeat 3 times or more till you are able to pipette the exact amount (.2pts each trial #3 for accuracy).

B. Use the 200 μ l pipettman (yellow cap). Follow the same steps as above except using a yellow tip. Repeat each measurement till you are able to deliver the correct amount (.2pts each trial 3). You may need to use the analytical balance if you get a weight of 0.00g.

C. Use the 20 μ l pipettman (yellow cap). Follow the same steps again (.2pts each trial 3).

D. Make unit conversions in the starred columns (.2pts each).

E. Mastery of all 3 pipettes (.6 pts or .2 pts each) Mastery total _____

p1000 pipette – blue cap		trial 1	trial 2	trial 3	
volume μ l	volume ml*	weight g	grams	grams	weight mg*
1000 μ l	1.0ml				
500 μ l	0.5ml				
200 μ l					
p200 pipette – yellow cap		trial 1	trial 2	trial 3	mg*
volume μ l	volume ml*				
200 μ l					
100 μ l					
p20 pipette – yellow cap		trial 1	trial 2	trial 3	mg*
volume μ l	volume ml*				
20 μ l					
10 μ l					
5 μ l					

Convert μ l to ml tot. _____

Accuracy total _____ g to mg

total _____

TOTAL POINTS (5 pts) _____

APPENDIX K

POST INTERVIEW QUESTIONS

Interview Questions for Students

1. What lab skill training exercises benefited you the most?
2. Do you feel your perception of lab skills like pipetting accurately, metric conversions, problem solving skills, graphing skills, and data analysis skills are more relevant to your future courses and career than they were at the beginning of the course?
3. Did the self-assessing lab skill training tool affect your motivation to pipette accurately?
4. Do you think this was an effective way to teach how to use the micropipettes? Use of the different balances? How to make volume and weight metric conversions?
5. Are there additional lab skills that would be helpful to you? (how to make dilutions, pH, conversions from the English system to the metric system, etc).
6. Do you have any additional comments or suggestions about lab instruction?