

THE EFFECTS OF GUIDED INQUIRY ON UNDERSTANDING HIGH SCHOOL
CHEMISTRY

by

Julie Beth McDonnell

A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Masters of Science

in

Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

May 2013

STATEMENT OF PERMISSION TO USE

In presenting this professional paper in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the MSSE Program shall make it available to borrowers under rules of the program.

Julie Beth McDonnell

May 2013

DEDICATION

This project is dedicated to my loving family, without whose love, patience, and support I would have never made it though.

TABLE OF CONTENTS

INTRODUCTION AND BACKGROUND	1
CONCEPTUAL FRAMEWORK.....	3
METHODOLOGY	10
DATA AND ANALYSIS.....	18
INTERPRETATION AND CONCLUSION	42
VALUE.....	44
REFERENCES CITED.....	47
APPENDICES	49
APPENDIX A: Chemical Demonstrations List.....	50
APPENDIX B: Chemical Reactions Type Homework.....	52
APPENDIX C: Chemical Reaction Unit Quizzes	54
APPENDIX D: Single Replacement Lab	56
APPENDIX E: Five Types of Reactions Lab	59
APPENDIX F: Muddiest Point Probe for Classifying Reactions.....	61
APPENDIX G: Smores Exploration Activity.....	63
APPENDIX H: Gas Law Exploration Probe	65
APPENDIX I: Boyles Law Guided-inquiry Lab	67
APPENDIX J: Pre and Postassessment Questions	71
APPENDIX K: Student Survey Questions	74
APPENDIX L: Student Concept Interview Questions	77
APPENDIX M: Student Nonconcept Interview Questions	79
APPENDIX N: Student Observation Guide	81
APPENDIX O: Teacher Observation Guide.....	83
APPENDIX P: Journal Prompts for Teacher Reflection	86
APPENDIX Q: Summary of Teaching Goals Inventory	88
APPENDIX R: Project Implementation Timeline.....	90

LIST OF TABLES

1. Data Triangulation Matrix	16
2. Average Scores, Percent Change, and Normalized Gain of Pre and Postunit Assessments of High, Middle, Low-Achieving, and All Students.....	19
3. Percent Understanding of Concepts During Concept Interviews	22
4. Percentage of Responses for How Guided Inquiry Improved Problem-solving Skills .	26
5. Average Scores of Higher-Order Thinking Questions from Unit Preassessments and Postassessments for High, Middle, Low-Achieving, and All Students.....	29
6. Average Scores of Higher-Order Thinking Questions on Unit Tests for High, Middle, Low-Achieving, and All Students	31
7. Percentage of Responses for Reasons Why Students Did or Did Not Look Forward to Coming to Chemistry Class.....	36

LIST OF FIGURES

1. Perceived Understanding of Concepts with Student Survey Scores of High, Middle, and Low-Achieving Students	21
2. Average Problem-solving Scores of High, Middle and Low-Achieving Students for Nonintervention and Intervention Units	24
3. Comparison of Nonintervention and Intervention Student Observation Scores During Lab Activities	33
4. Student Ranking for Statement “I look forward to chemistry class” for All Students .	35
5. Post Intervention Guided Inquiry Recommendation Scores Given by Students	38

ABSTRACT

My project sought to address the problem of passive, unmotivated students who leave labs and class activities still holding on to misconceptions. In this investigation, guided-inquiry labs and class activities were implemented with the purpose of improving student understanding in high school chemistry. Process Oriented Guided-Inquiry activities, guided-inquiry labs, and online investigations were completed during the stoichiometry and gas laws units in two chemistry classes with 57 students. Pre and postunit assessments, pre and postunit student interviews, pre and postintervention student surveys, unit tests, instructor field observations, colleague observations, instructor weekly journaling, and pre and postintervention teacher surveys were used to evaluate the effectiveness of the intervention. Overall, students showed increased conceptual understanding and problem-solving skills, with low and middle-achieving students showing the most growth in those areas. While postunit assessments and unit tests did not show measurable improvement in higher order thinking skills following intervention, students demonstrated increased engagement during class activities. Both the students and the teacher also experienced an increase in motivation as a result of the guided- inquiry intervention. The results of this study encourage increased use of guided inquiry in all units of chemistry and the rewriting of existing labs and activities to promote more higher-order thinking and student-directed learning.

INTRODUCTION AND BACKGROUND

As I began to reflect on my teaching, I realized my students understand concepts the best when they ask and answer questions that are meaningful to them, rather than following a rote procedure in a cookbook-style lab. I also have noticed that laboratory exercises are the highlight of many of my students' chemistry experience. I also believe that students need to take away more from labs than just an interest in science. I recognized the need to advance class activities and labs to include more inquiry to help develop their inquiry skills. This realization led me to explore incorporating guided-inquiry class activities and labs into my curriculum to improve student understanding of concepts.

My project sought to address the problem of passive, unmotivated students who leave labs and class activities still holding on to misconceptions. By shifting the focus from teacher-directed to student-directed activities, I hope to gradually advance my students to more complex levels of science reasoning and higher order thinking skills, improving both conceptual understanding and problem-solving skills. This project is significant to my school as Illinois adopts new Common Core State Standards (CCSS), which emphasize information processing and thinking skills students need to be prepared in college and the workplace. Guided inquiry is not only an excellent tool to teach the skills represented in the CCSS, it is a way to increase conceptual understanding in science.

This study was conducted in two sections of 10th-grade regular level chemistry at Lake Park High School, a suburban high school near Chicago. A total of 57 students participated in the project. Both sections include a wide range of ability levels. While the school population is predominately White and middle class, there are increasing numbers of Hispanic and African

American students. Our school is in our fourth year of remediation for being a failing school according to No Child Left Behind.

My project focus question was: What are the effects of guided-inquiry class activities and labs in conjunction with the cycle of inquiry model on student understanding of high school chemistry? My project subquestions were as follows: what are the effects of guided-inquiry class activities and labs in conjunction with the cycle of inquiry model on students' problem-solving skills; what are the effects of guided-inquiry class activities and labs in conjunction with the cycle of inquiry model on students' higher order thinking; what are the effects of guided-inquiry class activities and labs in conjunction with the cycle of inquiry model on students' interest and motivation; what are the effects of guided-inquiry class activities and labs in conjunction with the cycle of inquiry model on my teaching and attitudes toward teaching?

For the purpose of this study, guided-inquiry activities refer to investigations and class lessons that teachers and students work together on to develop ideas. When students are first introduced to inquiry, both the questions for investigation and the process for answering them are decided by the teacher. As students progress, questions for investigation are still chosen by the teacher, but students assist the teacher with deciding how to proceed (Martin-Hansen, 2002). Students will gradually engage in more complex reasoning tasks as inquiry continues.

To help me complete this project, my capstone support team is composed of colleagues, administrators, friends, and family who have helped me in a variety of ways. Jewel Reuter, Ph.D. is my capstone advisor. Terrill Paterson is my MSU reader who helped me refine my data analysis. Nadia Pena is a chemistry colleague who agreed to observe both my intervention and nonintervention lessons and provide me with feedback. Leah Macnamara, another chemistry colleague who talked through my teaching strategies and activities. My mother, Donna Patterson,

is a retired special education teacher who acted as my sounding board for all my teaching questions and dilemmas, as well as an editor.

CONCEPTUAL FRAMEWORK

While the history of inquiry dates back to the early 1900s, it was not until 1996 that the National Science Education Standards brought inquiry to the forefront of science instruction. With the 2013 release of the finalized Next Generation Science Standards, engineering and scientific inquiry practices are now a focus for curriculum reform. Review of the literature indicates that students' conceptual understanding, higher order thinking skills, and attitudes towards guided inquiry increase when inquiry is implemented into the science classroom. To assist teachers in implementing these standards, many strategies and best practices have been identified to help teachers transform traditional, cookbook labs into authentic inquiry experiences and to incorporate inquiry into non-laboratory activities as well.

Inquiry is based on constructivist ideas; namely that students need to experience learning activities that allow them to construct their own knowledge to promote their thinking skills (Miri, David, & Uri, 2007). Human constructivists contend that classroom efforts need to focus on meaningful learning over rote learning (Mintzes, Wandersee, & Novak, 1998) and conceptual understanding of scientific ideas. This can be accomplished by encouraging students to construct useful knowledge that is applicable to the real world (Mintzes, Wandersee, & Novak, 2001). Inquiry has played a role in science programs since the early 1900s, when John Dewey declared that science should be taught not only as the accumulation of information, but as a way of thinking, as a process, and as a method (National Research Council, 2000). In Dewey's model, students should be active learners who study problems related to their experiences (Barrow, 2006).

One widely researched inquiry strategy used in high school chemistry courses is Process-Oriented Guided Inquiry Learning (POGIL). Moog and Spencer (2008) describe the POGIL learning environment as a place where “students are actively engaged in mastering the content and concepts of a discipline; at the same time they are developing important learning skills by working in self-managed teams on guided-inquiry activities designed specifically for this purpose and environment” (p.1). POGIL is student-centered, where the role of the instructor is to facilitate and the majority of the focus is on the activities of the students (Moog & Spencer, 2008). The two main goals of POGIL are to help students master content by constructing their own knowledge, and to develop important learning skills such as communication, critical thinking, problem solving, and assessment (Moog & Spencer, 2008). Materials used in POGIL are based on the learning cycle paradigm developed by Karplus (1977). The learning cycle has three phases: Exploration, Concept Invention, and Application. In the Exploration phase, students are presented with a discrepant event from which they generate and test hypotheses in order to understand what happened (Moog & Spencer, 2008). In the Concept Invention phase, students, with the help of their teacher, construct their own understanding of a concept and learn required vocabulary. Moog and Spencer (2008) point out that this phase is very different than a traditional lecture presentation in that teachers and students engage in discussion, not only direct instruction. In the Application phase, students apply the newly learned concept to new situations, requiring students to further discuss and process (Moog & Spencer, 2008). Renner, Abraham, and Birnie (1988) found that each phase of the learning cycle is necessary. Furthermore, Renner et al. discovered that “explaining a concept before providing experiences with materials results in little or no conceptual understanding” (p.56). Therefore, because teaching by telling does not work, using discrepant events prior to explanation is critical.

Research has shown that the Exploration, Concept Invention, Application learning cycle is superior to the inform, verify, practice procedure of traditional teaching (Renner et al., 1988). However, research has also shown that all three learning cycle phases are necessary in developing understanding of a concept, and that those phases have a definite sequence and structure (Renner et al., 1988). In a study of 62 twelfth-grade physics students, Renner et al. tested the necessity and sequence of each phase of the learning cycle. Renner et al. found that students do not understand a concept just because it has been explained to them. Instead, when students are given concrete experiences (the exploration phase) before the explanations are provided, students understand the concept better. In other words, “the exploration and [concept] invention phases provide more conceptual understanding than does just telling the students what the concept is at the beginning of the learning cycle” (p. 49). Renner et al. also caution that the exploration phase alone is “insufficient to produce maximum concept learning” (p.49). Discussion must follow the exploration phase to address misconceptions and introduce vocabulary. The research of Renner et al. show that each phase of the learning cycle is necessary to build conceptual understanding, and that the exploration phase must occur first.

Guided-inquiry instruction has been shown to improve a student’s conceptual understanding of science. Thacker, Kim, Trefz, and Lea (1994) investigated how inquiry-based teaching methods could improve the conceptual understanding of students in a college level introductory physics course. Thacker et al. compared three traditional lecture-based physics courses with an inquiry-based course. The inquiry-based course was comprised of 24 elementary education majors. In contrast, the traditional courses contained honors physics, engineering physics, and physics for non-science course totaling 309 students. Students in the inquiry class worked cooperatively in small groups to “develop their own conceptual models based on their

own experiments” (Thacker et al., 1994, p. 629). Student performance was measured by comparing results on a qualitative synthesis problem used by each class on the midterm exam. Thacker et al. found that students in the inquiry class scored much higher on the problem than students in any of the other classes: 29% of the inquiry students had the problem completely correct, as opposed to 4% of the honors students, 2% of the engineers, and 0% of the nonscience majors. These scores are even more impressive considering that the elementary education majors “initially have less knowledge of physics than the other students” (Thacker et al., 1994, p. 632). Thacker et al. attributed this performance difference to the fact that inquiry-based instruction allows for more time and discussion to be spent on a topic, and more interaction between students. Furthermore, inquiry gives students an environment to develop their own conceptual understanding. These results led Thacker et al. to consider the possibility that “inquiry-based instruction is superior to traditional instruction” (p.632).

Beyond labs, use of computer simulations in guided-inquiry instruction can also increase conceptual knowledge of science. Cakir (2011) studied the effects of using a computer-based investigation to develop understandings of basic Mendelian genetics. The study followed 12 preservice teachers as they completed the investigation as part of a required science methods course. Students worked in pairs to use the computer simulation to collect and interpret data on inheritance patterns. Students used data from the program to have classroom discussions on inheritance concepts as well as complete and present inquiry projects. Cakir found that after using the simulation, posttest scores improved by 28%. In general, Cakir found that using the simulation “promoted students’ conceptual understanding of Mendelian genetics and understandings of scientific inquiry” (Cakir, 2011, p. 156).

In addition to improving conceptual understanding, science inquiry activities provide teachers with opportunities to improve students' higher order thinking skills. Miri, David, and Uri (2007) investigated how purposely teaching higher order thinking skills could affect student ability to think critically. In their study, Miri et al. (2007) used Bloom's Taxonomy to define higher order thinking. Recall is the lowest order thinking while analysis, evaluation, and synthesis would be considered higher order thinking. In addition, Miri et al. also reported skills used in inquiry (i.e. problem-solving skills, inferring, estimating, predicting, question posing, and decision making) as higher order thinking skills. Miri et al. researched 177 students in both science and nonscience classes in Israel from tenth to twelfth grades. Miri et al. found a statistically significant improvement in critical thinking skills in classes where teachers intentionally taught the skills over control groups. Specifically, it was found that three inquiry-based teaching strategies promoted higher order thinking skills: dealing with real-world cases, encouraging open-ended class discussions, and fostering inquiry-oriented experiments (Miri et al., 2007). Finally, the study revealed that students were able to transfer the critical thinking skills learned in science to other domains, suggesting that skills learned through inquiry can be applied in other areas of life.

Student motivation and engagement increase more from guided inquiry than traditional teaching methods. Cavallo and Laubach (2001) investigated 119 tenth-grade biology student's attitudes towards enrolling in elective science courses. Cavallo and Laubach found that students in classrooms where teachers effectively used the learning cycle had more positive attitudes than students in traditional classrooms. Many more females who experienced guided inquiry planned to continue taking science courses than females from traditional teaching experiences. The study also found that males students from traditional teaching environments had "more negative

perceptions of science” (p. 1029) than males from guided-inquiry classrooms. These findings prompted Cavallo and Laubach to conclude that “using the [guided-inquiry] model as it was originally designed may lead to more positive attitudes and persistence in science among students” (p. 1029).

Using guided inquiry can benefit teacher beliefs as well as students. While the literature supports the benefit of inquiry teaching, few teachers implement inquiry into their curriculum (Cheung, 2011). Cheung’s study developed a guided-inquiry scale (GIS) to measure teacher beliefs about implementing guided inquiry into high school chemistry. The scale measured the value of guided-inquiry labs, the limitation cookbook-style labs, and implementation issues. Data were collected from 200 Hong Kong high school chemistry teachers. Regardless of teachers’ levels of experience, the study found that teachers who do not use guided inquiry believed students disliked it and that it was not feasible for students to design their own experiments. The study suggested that creating professional development opportunities that address implementation issues rather than the value of inquiry teaching could convince more teachers to try guided inquiry.

In a separate study, pre-service teachers’ beliefs about learning science through inquiry before and after inquiry-based instruction were studied (Tatar, 2012). Researchers found that even when pre-service teachers had initially negative views of inquiry-based instruction on limited prior knowledge or experience with inquiry, engaging in inquiry-based instruction changed their beliefs. After four weeks of inquiry-based instruction, participants “gained knowledge and skills in inquiry activities, and these acquisitions contributed to the development of [their] beliefs” (Tatar, 2012, p. 259). As a result of instruction, pre-service teachers now enjoyed learning science through inquiry and thought that inquiry-based instruction increased

long-term knowledge of concepts. The authors propose that for teachers to use inquiry in their classrooms, teacher education programs must provide pre-service teachers with opportunities to gain experience with inquiry-based instruction (Tatar, 2012). The work of Cheung and Tatar (Cheung, 2011; Tatar, 2012) show that teacher attitudes and motivation towards teaching with inquiry improve only when teachers have access to professional development on inquiry-based instruction and feel comfortable using inquiry themselves.

To help address the issues of implementation and feasibility, many strategies and activities for guided inquiry have been created. Guided-inquiry activities can span a continuum from teacher centered to student centered (NRC, 2000). Martin-Hansen (2002) states that students think more when teachers allow them to make choices and decisions during classroom investigations. As such, Martin-Hansen offers suggestions on how to make activities more student centered: students devise procedures, students create data tables, students determine how data should be collected, and students explain how an experiment could be improved for a better investigation. Cakir (2011) showed that using computer simulations can enhance inquiry instruction and improve conceptual understanding. Mintzes et al. (2011) advocate for the use of student constructed work products including concept maps and written and oral reports, as well as small group assessment on projects where each student has a defined role. Furthermore, Miri et al. (2007) demonstrated the importance of using open-ended discussion as a component of guided inquiry. Volkmann and Abell's (2003) research uses the NRC's five essential features of inquiry to transform cookbook labs into inquiry experiences. Volkmann and Abell created a two stage inquiry analysis and adaptation process for evaluating and revising instructional materials. Once a lab has been assessed using the inquiry analysis tool, the adaptation principles provide 10 actions teachers can use to address the lack of inquiry (Volkmann & Abell, 2003). In addition,

the research recommends postponing teacher explanations until the end of the lab or demonstration to shift the responsibility of explaining to the students (Volkman & Abell, 2003). Finally, classroom tested POGIL lessons and activities are included on the *POGIL Project* online. POGIL strategies include working in small groups with defined group roles, using formative assessment probes with discrepant events to introduce concepts, and using discussion to address misconceptions and further student understanding. Many of the strategies I used in my intervention are based on the work of the *POGIL Project* (2012).

Reviewing the history of inquiry shows that while standards and clear frameworks exist for inquiry, teachers are still hesitant to implement inquiry into their own practice. Because guided inquiry has the power to improve students' conceptual understanding and higher order thinking skills as well as their attitudes towards science, it is important that teachers be made aware of strategies and tools that exist to help transform current practice into authentic inquiry experiences.

METHODOLOGY

Project Intervention

To assess the outcomes of my intervention, data were collected from a nonintervention and two intervention units for comparison. The nonintervention unit was taught with a traditional teacher-centered approach while the intervention units used student-centered guided-inquiry labs and classroom activities. 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.

The nonintervention unit, chemical reactions, focused on identifying reaction types, balancing equations, and predicting products of a reaction. Instruction was primarily delivered

with direct instruction lectures. I worked out example problems on the board to balance and predict products for each reaction type, including synthesis, decomposition, single replacement, double replacement, and combustion. For each reaction type, I performed a demonstration, writing a balanced equation to illustrate each one. The demonstration list with equations is in Appendix A. Students worked independently to complete daily homework worksheets to practice the concepts learned in class. These assignments were graded in class the following day for correctness, so students could learn from their mistakes. An example of student homework is in Appendix B. Three short quizzes were given throughout the unit so that students could demonstrate mastery of each of the following skills: balancing equations, identifying reaction types, and predicting products of a reaction. These quizzes are in Appendix C. Students performed two labs in this unit. The first lab on single replacement reactions had students determine the reactivity series for copper, magnesium, and zinc. The second lab has students observe four different types of reactions. In these traditional cookbook labs, students worked in pairs to perform prescribed procedures, complete data tables, answer data analysis and conclusion questions, and write and balance chemical reactions. These two labs are in Appendix D and E, respectively. Throughout the nonintervention unit, students completed CATs, such as the muddiest point and one sentence summary to keep both me and the students informed as to how they were progressing. The muddiest point probe for classifying reactions is in Appendix F.

The two intervention units on stoichiometry and gas laws employed guided-inquiry class activities and labs. In the intervention units, instead of the students passively receiving information from me, students discovered most knowledge for themselves. To accomplish this, I employed the cycle of inquiry model, which includes the following stages: Exploration, Concept Invention, and Application. During the exploration phase, I used discrepant events, diagrams,

and formative assessment probes to focus student attention and generate student interest. To introduce the concept of limiting reactants, students completed an activity about s'mores, adapted from *S'more Chemistry* (Illinois State University, 2012). Working in small groups, students answered a series of guiding questions about making s'mores, calculating how many graham crackers, marshmallows, and chocolate pieces were needed in various situations. These guiding questions ensured that students built on prior knowledge and reached appropriate conclusions. After answering questions as a group, the class reconvened to discuss limiting reactants, excess reactants, and theoretical yields while eating s'mores. Only after students shared their ideas, did I lecture about limiting reactants and explain the concept using chemical quantities instead of food. The s'more exploration activity is in Appendix G, and an exploration probe used in the gas law unit is in Appendix H.

During the Concept Invention stage, inquiry-based labs and simulations were developed to allow students the chance to form predictions and test hypotheses, as well as to introduce them to new material. In the stoichiometry unit, students completed online *pHet* simulations (Lancaster et al., 2011) to determine coefficients and discover the meaning of both limiting reactants and the law of conservation of mass. In the gas law unit, students completed guided-inquiry labs to determine Charles' and Boyle's law for themselves. Students also completed the *Gas Properties pHet* simulation to determine both Lussac's law and the Ideal Gas Law.

Also during the Concept Invention phase, in which teachers help students to construct conceptual understanding and acquire vocabulary (Renner et al., 1988), I helped lead both small group and whole class discussions to process data collected in lab or simulations and further explained scientific concepts brought up by our initial investigations. Through minilessons, I modeled how to complete calculations, and students worked in groups to complete calculations.

Students also read articles related to the concepts studied and answered questions that required them to infer from the text, rather than recall information.

During the Application phase, students expand the meaning of concept through further experiments, readings, and problem-solving activities (Renner et al., 1988). Students applied knowledge of the gas laws to performance assessments such as the collapsing can lab and reported out their results to the class. The application phase is meant to be the most student-directed phase of the learning cycle, where the most reflection and critical thinking occurs. Throughout both intervention units, students completed similar assessments as in the nonintervention unit, to continue to keep students aware of their learning and to help me understand where I needed to close the feedback loop of understanding.

To create materials for the guided-inquiry activities and labs used during the intervention units, I reworked existing cookbook labs into authentic inquiry experiences. To do this, I used the inquiry analysis tool by Volkmann and Abell (2003) to evaluate existing labs and pinpoint areas that needed revision. I then used Volkmann and Abell's adaptation principles to make changes. Key revisions I implemented to make labs and activities more inquiry-based include: restating the purpose of the lab as a question, allowing students to help develop procedures, taking away data tables, moving teacher explanations to after the lab, engaging students in data analysis, and allowing students opportunities to present and defend their explanations to their peers.

In addition, I used Bloom's Taxonomy (Bloom, 1956) to purposely write higher order thinking questions for use in class discussions, lab activities, and online simulations and article reading assignments. In each activity, questions were scaffolded to ease students in to critical thinking. By using scaffolding, I made sure that students were introduced to inquiry gradually, so

that my students gradually took on more responsibility and completed increasing complex scientific reasoning tasks.

Using guided inquiry can increase higher order thinking and problem-solving skills because students are forced to create knowledge for themselves, rather than rely on the teacher to give them all the answers. By engaging in scaffolded-inquiry experiences, students gradually complete more complex science reasoning tasks. Guided inquiry allows students to gather and analyze data, create and evaluate explanations based on evidence, and communicate explanations with their peers. These tasks require students to think more critically and work more cooperatively than is required in traditional teacher-centered teaching. In addition, student interest and motivation are likely to improve using guided-inquiry techniques because students get to make decisions about investigations and take on a more active learning role during hands on activities.

Data Collection Instruments

Data were collected from two sections of 10th-grade regular level Chemistry at Lake Park High School in Roselle, Illinois, a middle class suburb located 25 miles west of Chicago. A total of 57 students participated in this project. There were 28 (49%) females and 29 (51%) males. Of the students, 40 were Caucasian, eight students were Hispanic, five students were Asian, and four students were African-American. Only one student received 504 accommodations. Because chemistry is a graduation requirement, both sections had a wide range of ability levels. Students in both sections had a wide range of reading and math abilities, ranging from students in all honors and advanced classes to students who are in prealgebra. Even though students range in ability level, most students value education and want to do well. Students worked well in small groups, with only a select few students needing guidance to stay on task. Students were generally

respectful and outgoing, and both sections have a positive learning environment. I chose this group of students because I felt that all students in this group could benefit from instruction that focused on improving higher order thinking skills, and that learning these skills would be an appropriate and achievable goal for these students.

Data from multiple sources were collected for each project question to allow for triangulation. The data triangulation matrix detailing data sources is shown in Table 1. By gathering information on each project question from a variety of sources and using various instruments, I ensured that I gathered a wider range of perspectives. These perspectives gave me greater insight into each question than could have been gained by using only a single data source.

Table 1
Data Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
<i>Primary Question:</i>			
What are the effects of using guided-inquiry class activities and labs on student understanding of high school chemistry?	Pre and postunit student assessments	Pre and Postunit student interviews with concept maps	Pre and postintervention student surveys on their perception of understanding
<i>Subquestions:</i>			
Students' problem-solving skills?	Pre and postunit student assessments	Pre and Postunit student interviews with concept maps	Pre and postintervention student surveys
Students' higher order thinking?	Pre and postunit student assessments	Pre and Postunit student interviews with concept maps	Unit Tests
Students' interest and motivations?	Instructor field observations	Pre and Postintervention student interviews	Pre and postintervention student surveys
My teaching and attitudes to teaching?	Nonintervention and intervention observations by colleagues	Instructor weekly reflection journaling with prompts	Pre and postintervention teacher surveys

To measure student understanding, all students completed a preunit assessment prior to the start of both intervention and nonintervention units. These same questions showed up again on the unit test in the free response section. The list of questions used on pre and postunit assessments can be found in Appendix J. All students also completed surveys on their perception of understanding on *Google Docs* before and after intervention. The list of survey questions is in Appendix K. Additional information about student understanding was gathered using interviews. To select students from different achievement levels, student's first semester grades were sorted on Excel. Scores were divided into three groups: high achieving (100-90%), middle achieving

(89-79%), and low achieving (78-65%). Two students were selected from each group to be interviewed based on their likelihood to participate in an open and honest discussion. These same students were again interviewed during postintervention interviews and for all interviews. Interviews were recorded so that additional clarification questions could be asked. Notes were also taken as a backup for the recording. The list of concept interview questions is in Appendix L. To measure students' problem-solving skills and higher order thinking, data were collected from unit pre and postunit assessments. These assessments consisted of eight short answer questions, covering all levels of Bloom's Taxonomy. Scores on higher order thinking questions were tallied, and averages for each achievement level were calculated.

To measure student interest and motivation, I used the above mentioned survey (Appendix K) and interviewed students pre and postintervention. A list of nonconcept interview questions is in Appendix M. I also observed and collected field notes for each class during one lab activity per unit. I observed the five types of reactions lab during the nonintervention unit, the s' more explore activity during the stoichiometry intervention unit, and the Charles' law activity for the gas law intervention unit. The student observation guide is in Appendix N.

To assess my own teaching and attitudes towards teaching, my colleague observed one lesson from both the nonintervention stoichiometry unit and the intervention gas law unit. The teacher observation guide she used is in Appendix O. I reflected on my own attitudes towards teaching by writing weekly journal reflections. The journal prompts I used for these reflections are in Appendix P. In addition to weekly journaling, I also took the Teaching Goals Inventory (Angelo & Cross, 1993) before and after intervention to measure how my overall goals for teaching have changed as a result of this intervention. A summary of the Teaching Goals Inventory is in Appendix Q.

To analyze the data I have collected, I graphed pre and postunit assessment scores to show growth by achievement level. I also analyzed my department's unit tests by using Bloom's Taxonomy to determine if questions were low or higher order questions. I analyzed student performance on tests to determine the percentage of higher order thinking questions students answered correctly. The purpose was to measure the effect guided inquiry had on student ability to answer higher order thinking questions.

For each survey question using a Likert scale inventory, I was able to graph the data to measure the difference in responses. Qualitative data provided important information as well. Student responses during interviews were analyzed for trends and repeated comments. Student interviews also provided further insight on intervention techniques that could not be represented with a number. Reading through field notes of observations provided evidence of students' engagement and revealed further trends and patterns. Analyzing journal entries showed changes in my focus over the six week period, and comparing pre and postintervention Teaching Goals Inventory scores determined the effect the project had on my overall attitudes and goals in teaching.

This action research project started the last week of January. The project took seven and one half weeks to complete. Each unit (one nonintervention unit followed by two intervention units) lasted two and a half weeks (12 x 48-minute class periods). The exact timeline is shown in Appendix R.

DATA AND ANALYSIS

Data from the nonintervention and intervention units were compared to determine the effects of guided-inquiry class activities and labs on student understanding of chemistry

concepts. Data from multiple sources were collected for each focus question and subquestion to allow for triangulation.

The data collected from unit pre and postunit assessments allowed me to calculate percent change in understanding of concepts for the nonintervention and intervention units. These assessments consisted of eight short answer questions, covering all levels of Bloom's Taxonomy. Average scores, percent change, and normalized gain scores can be found in Table 2. In general, students showed growth during all three units; however, the growth during the intervention units was greater than the growth during the nonintervention unit.

Table 2
Average Scores, Percent Change and Normalized Gain of Pre and Postunit Assessments of High (n=20), Middle (n=22), Low-Achieving (n=15), and All Students (N=57)

		Achievement Level			
		Low	Middle	High	All
Nonintervention	Preunit	3.37	5.33	6.71	5.27
	Postunit	13.39	20.16	23.67	19.72
	% change	296.83	278.24	252.76	274.13
	Normalized Gain Score	0.33	0.50	0.57	0.48
Intervention Unit 1	Preunit	1.04	1.80	2.47	1.84
	Postunit	10.97	15.60	21.41	16.44
	% change	954.95	766.67	767.53	795.84
	Normalized Gain Score	0.33	0.46	0.63	0.49
Intervention Unit 2	Preunit	3.07	3.48	4.89	3.87
	Postunit	15.71	19.56	22.88	19.54
	% change	411.63	462.56	367.34	404.90
	Normalized Gain Score	0.42	0.54	0.60	0.52

Note. All assessments scored out of 30 points.

In both intervention units, students across all achievement levels improved their percent increase in comparison with the nonintervention unit. This suggests that the guided-inquiry

intervention had a positive effect on student assessment scores. Analyzing scores by student achievement level gives further insight into percent changes in knowledge. Average scores and percent change for high, middle, and low-achieving students can also be found in Table 2. Table 2 shows that students in all achievement levels had greater percent improvements during the intervention units over the nonintervention unit. During intervention unit 1, low-achieving students had the highest percent improvement, while middle-achieving students had the highest percent improvement in intervention unit 2.

Preassessment scores for intervention unit 1 were much lower than the other units. This is because students had more background knowledge on chemical reactions and gases from previous instruction than they did on stoichiometry. For this reason, the percent improvement for intervention unit 1 may have had an increase because these scores had more room for improvement. By including a normalized gain score, one can see the fraction of available improvement obtained. The normalized gain values are also found in Table 2.

Table 2 shows that both low-achieving and middle-achieving had a decreased normalized gain in intervention unit 1 when compared to nonintervention. These decreases may be explained by low and middle-achieving students becoming accustomed to learning with the POGIL process and were still developing their abilities. High-achieving students showed an increased gain from nonintervention to intervention unit 1 and to intervention 2. This increase suggests a sustained improvement in understanding. In contrast, all achievement levels improved their gain from nonintervention to intervention unit 2, which suggests an increase in understanding with POGIL. Of these gains, low-achieving students showed the highest improvement; with middle-achieving students have the next greatest improvement. This suggests that the guided-inquiry intervention

might be more beneficial to improving low and middle-achieving student performance without being detrimental to high-achieving students.

Survey data showed that students' level of perceived understanding relates well to their achievement on pre and postunit assessments. Students were asked to rate their level of understanding of each unit. By asking students to rate their perceived understanding, one can compare perceived understanding to actual performance. Figure 1 showed perceived understanding scores for nonintervention and intervention units.

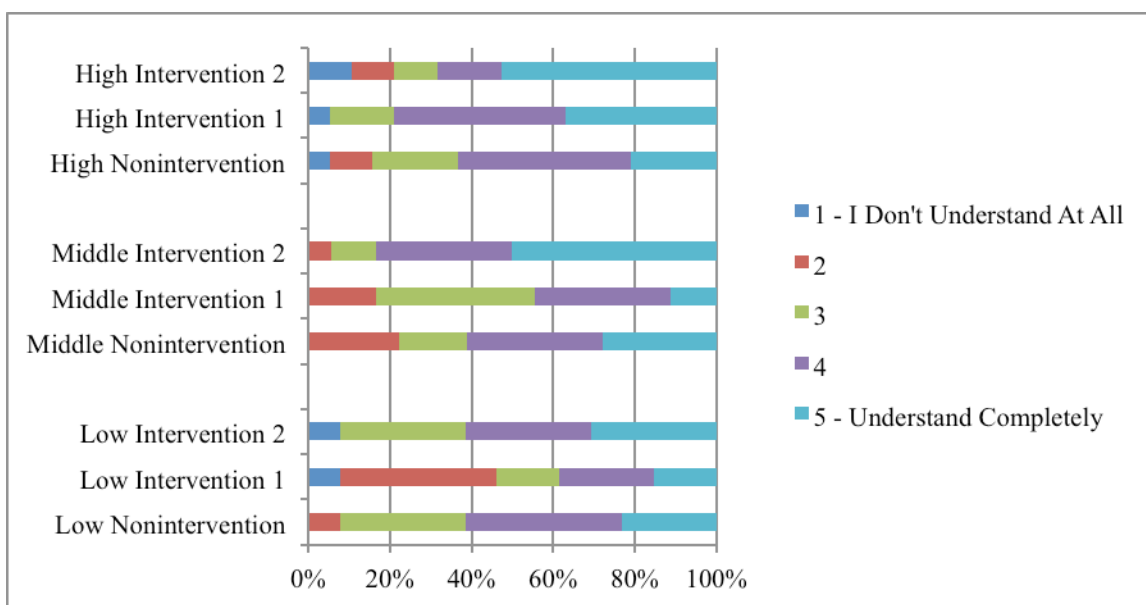


Figure 1. Perceived understanding of concepts with student survey scores of high ($n=20$), middle ($n=22$) and low-achieving students ($n=15$) for nonintervention and intervention units. *Note.* Likert Scale 5= I understand completely to 1= I don't understand at all.

Results in Figure 1 showed that overall, students' perception of understanding with intervention unit 2 on gas laws was the best with the most students "completely understanding" this unit. This intervention unit had the most POGIL activities and guided-inquiry labs. A middle-achieving student explained that in intervention unit 2, "all the labs and demos were really helpful because they showed us firsthand how the law worked and what it was." With

respect to achievement level, high-achieving students perceived that they understood both intervention units better than the nonintervention unit. Middle-achieving students thought they understood intervention unit 1 less than the nonintervention, but intervention unit 2 better than nonintervention. Low-achieving students perceived that they understood nonintervention and intervention unit 2 equally, but understood intervention unit 1 the least. Low and middle-achieving students cited “the math calculations and *t*-charts” as the reason they understood the stoichiometry in intervention unit 1 the least. These perceived understanding ratings correspond with the overall normalized gains seen in postunit assessments.

Interviewing students allowed me to gather more information about their understanding of key unit concepts. Questions such as “why do we balance equations,” “explain why we do stoichiometry,” and “explain the relationship between pressure and volume of a gas” were asked. Six students (two at each achievement level) were interviewed each unit. For each question dealing with conceptual understanding, student responses were ranked as showing no conceptual understanding, basic understanding, or advanced understanding. Percentages of student understanding from interviews are shown in Table 3.

Table 3

Percent Understanding of Concepts during Concept Interviews (N=6)

Level of Concept Understanding	Nonintervention Unit	Intervention Unit 1	Intervention Unit 2
None	33	16	16
Basic	66	33	50
Advanced	0	50	33

During the nonintervention unit, students had the least number of advanced responses, and the highest number of responses indicating no understanding. For example, a low-achieving

student on the nonintervention post interview said “I know how to balance equations; I just don’t know why we do it.” A high-achieving student responded that “we balance equations to get the same number of atoms on both sides” but could not relate balancing equations to the law of conservation of matter. During intervention units, I observed that students increased their ability to explain their thinking. The percentage of students with responses indicating no understanding decreased, while advanced understanding responses increased. When asked about the relationship between pressure and volume during intervention unit 2, the same low-level student responded “If you decrease the volume, the molecules have less room to move around and collide more, causing the pressure to increase. It’s an indirect relationship.” This same student who could previously not verbalize any explanation for balancing equations could now give detailed descriptions with correct vocabulary. These responses indicate that guided-inquiry activities improve this student’s ability to explain her conceptual understanding.

Data from pre and postunit assessments, surveys, and interviews showed that conceptual understanding of all students improved with the guided-inquiry intervention. Assessment data revealed that low and middle-achieving students showed the most improvement in scores. Surveys showed that overall students felt they improved their understanding from nonintervention to intervention unit 2. Interviews with students confirmed these results, as the number of responses indicating no understanding decreased with intervention units, and the number of advanced understanding responses increased with intervention units.

The effects guided inquiry had on students’ ability to problem solve is closely related to the results seen with student conceptual understanding. To measure the change in student problem-solving skills, data were collected from unit tests, pre and postintervention student surveys, and interviews during nonintervention and intervention units.

Unit tests for both nonintervention and intervention units consisted of a multiple-choice and problem-solving portion. Problem-solving portions from each unit test were scored, and average scores for each student achievement level are shown in Figure 2.

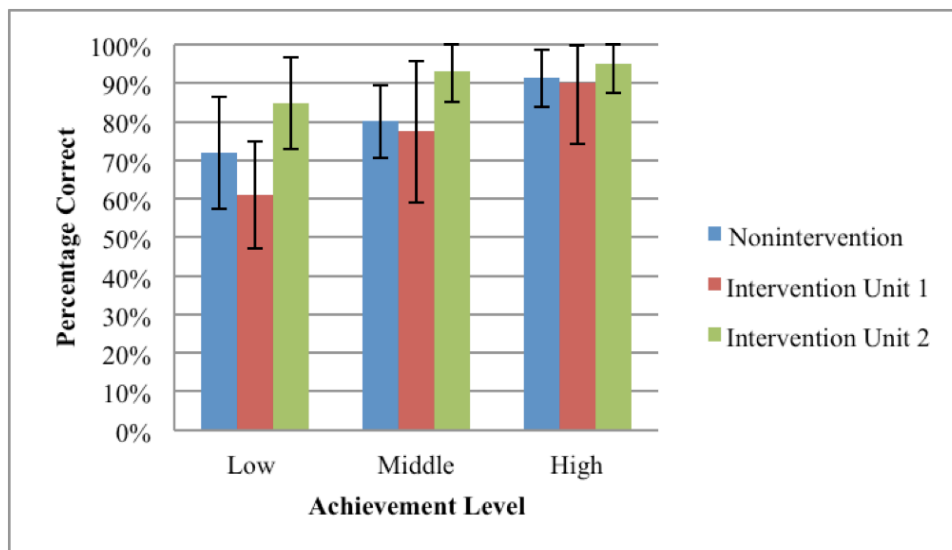


Figure 2. Average problem-solving scores of high ($n=20$), middle ($n=22$) and low-achieving students ($n=15$) for nonintervention and intervention units.

Results in Figure 2 show that scores for all three achievement groups followed a similar pattern. For low-achieving students, scores for intervention unit 1 were 10.96% lower than nonintervention, while scores for intervention unit 2 were higher than both nonintervention and intervention unit 1. For middle-achieving students, the decrease from nonintervention and intervention unit 1 was 2.58%, with an increase in intervention unit 2. High-achieving students saw only a 1.27% decrease from nonintervention to intervention unit 1. There are many possible reasons for this trend. All students experienced an adjustment period during intervention unit 1, where they first encountered POGIL activities. This was the first time students had to rely on their group for advice and guidance instead of the teacher, to work out problems and generate explanations. Many students initially struggled with learning in this way, becoming frustrated

and asking me to give them the answer. These results relate well with the student perceived understanding scores in Figure 1, as low and middle-achieving students ranked intervention unit 1 as the unit they understood the least. Low-achieving students showed the sharpest decline in problem solving from nonintervention to intervention unit 1 with a negative percent change of 15%. In contrast, middle-achieving and high-achieving students showed smaller decreases of 3% and 1%, respectively. This decline is mostly likely because low-achieving students were learning some of these problem-solving skills for the first time, whereas middle and high-achieving students were practicing problem-solving skills they already had. All achievement groups performed the best on the intervention unit 2 problem-solving section. By intervention unit 2, all students were accustomed to working in small groups with defined roles to solve problems, and had gained experience writing their own procedures and drawing conclusions from data they collected. Low and middle-achieving students showed the most improvement from nonintervention to intervention unit 2 with percent changes of 18% and 16% respectively, while high-achieving students showed the least improvement with a percent change of 4%. These data suggest that low and middle-achieving students gained the most problem-solving skills from the guided-inquiry intervention.

Survey data supports the evidence that students gained problem-solving skills from the guided-inquiry intervention. On the postintervention survey, students were asked the question “How did guided-inquiry labs and activities improve your problem-solving skills?” Eighty three percent of students responded that guided inquiry improved their problem-solving skills. Table 4 shows a summary of their responses.

Table 4
Percentage of Responses for How Guided Inquiry Improved Problem-solving Skills (N=57)

Reason Cited for Problem Solving Improvement	Percentage
Provided Better Lab Data	4.4
Understood Purpose of Lab Better	26.7
Made Me More Independent	24.4
Helped Me Organize My Thoughts	8.9
Benefitted From Writing Own Procedure	26.7
Made Me Think More	8.9

Table 4 shows that the majority of students thought they benefitted from writing their own procedures for labs. By writing their own procedure students “had to think about the lab and the reason why we were doing it.” Students also wrote that “I feel like it helped us because we understood what the point of the lab was when we made the procedures and data tables ourselves.” Guided-inquiry labs helped students to understand lab concepts more because they designed the labs themselves rather than simply following a set of procedures. Furthermore, students felt that guided inquiry made them more independent thinkers. One student wrote, “they made me have to think of the steps to take instead of being told what steps to take. It made us more independent.” In short, guided inquiry improved students’ problem-solving skills because it forced students to ask and answer their own questions, and work as a team to solve problems.

Interview data also suggest that student problem-solving skills improved with each unit. In each postunit interview, students were asked to solve a problem and talk through their thought process. During the nonintervention interview, when asked to write and balance a chemical reaction for sodium metal and chlorine gas, a low-level student could only write the equation after prompting for each element. She had great difficulty explaining her thought process, and

only by asking follow up questions such as “why did you give chlorine a subscript of two” would she tell me “because it’s a diatomic.” This student was unable to correctly balance the equation she had written. When asked what activities during the nonintervention helped her problem solve, she responded that she couldn’t remember.

After intervention unit 1, this same student was asked to complete a limiting reactant problem and calculate how much product would be produced. She showed an improvement in explaining her thought process, by telling me she was starting by making a t-chart, and that she needed to find how many grams of zinc and oxygen she needed, to see which one ran out first. She was correctly able to work the problem without any prompting from me. She had correct calculations and was able to identify which reactant was limiting and which was excess, using those vocabulary words. When asked how she knew, she said, “Because I need 50g and I have 100g, I have enough.” When asked what activities during intervention unit 1 helped her, she said “the POGIL activities were difficult to solve, but working in groups helped.”

After intervention unit 2, this same student seemed more confident in her responses. She was able to correctly the relationships between pressure, volume and temperature, as well as give examples of these relationships. When asked to describe the factors that could increase the pressure of a contained gas, she responded “you could add more gas, or decrease the volume of the box. Both things would cause more collisions, which would up the pressure.” She again cited POGIL activities and working in teams as reasons why she felt her problem-solving skills had improved.

Similar trends were observed when interviewing middle-achieving students after each unit. After the nonintervention unit, a middle-achieving student listed one-on-one teacher explanations during science tutoring to help her problem solve. After intervention unit 2, this

student mentioned that POGIL activities helped her problem solve because these activities “make you think more, and it just helps you think more for yourself”. She explained that she preferred POGIL activities over lecture, because she felt like she remembered things better if she did a POGIL activity before the teacher explanation. She explained that “instead of just telling us what we should know, I like that we are in groups and it’s like we’re teaching ourselves and if we have questions you help us.” After intervention unit 2, this student could correctly identify three ways to increase the pressure of a gas: “you can increase the temperature, you could add more gas, or if you made the space smaller.” She could correctly identify relationships between pressure, volume and temperature, and said that labs “demonstrated the gas laws”, and “made it easy to figure out the relationships.” She also said that “writing our own procedure and collecting the data ourselves helped, because we knew what we were looking for, just not told what we’re looking for.” High-achieving students demonstrated excellent problem-solving skills throughout both nonintervention and intervention unit interviews, implying that guided-inquiry activities helped these student practice skills they already had rather than acquire them. These results also suggest that perhaps the problems given to high-achieving students were not difficult enough for them to show improvement. It is possible that the assessment had a ceiling that limited their improvement potential, resulting in only modest achievement gains.

Data from unit tests, surveys and interviews all showed that low and middle-achieving students gained problem-solving skills over the course of the guided-inquiry intervention. Low and middle-achieving students showed the most improvement on problem-solving portions of tests, and interviews with these students showed an increased ability to explain their thought process when solving a problem. These students also credited guided-inquiry activities and working in groups as reasons for their improved problem-solving skills. High-achieving students

showed only modest improvement on unit tests. Changing assessments to include more difficult problems may have allowed high-achieving students to show more growth. Although high-achieving students agreed that guided-inquiry activities made them think more than traditional instruction, they demonstrated developed problem-solving skills in both nonintervention and intervention units.

To measure the effects of guided inquiry on students' higher order thinking skills, data were collected from pre and postunit assessments, unit exams, and interviews during nonintervention and intervention units. Preassessment and postassessment average scores and normalized gain for higher order thinking questions can be found in Table 5.

Table 5

Average Scores of Higher Order Thinking Questions from Unit Preassessments and Postassessments for High (n=20), Middle (n=22), Low-Achieving (n=15), and All Students (N=57)

		Achievement Level			
		Low	Middle	High	All
Nonintervention	Preunit	4.17	6.52	7.72	6.39
	Postunit	78.57	59.42	63.74	65.67
	Normalized Gain	0.744	0.529	0.56	0.593
Intervention Unit 1	Preunit	5.29	3.87	2.81	3.82
	Postunit	67.31	51.49	45.07	53.07
	Normalized Gain	0.62	0.476	0.423	0.493
Intervention Unit 2	Preunit	17.42	19.83	10.05	15.78
	Postunit	59.85	60.91	56.49	59.29
	Normalized Gain	0.424	0.411	0.465	0.435

Table 5 shows all student scores decreased in intervention units 1 and 2 when compared with nonintervention. High-achieving students showed a small increase in intervention unit 2 over unit 1, but this gain was still less than nonintervention. Overall, student averages on higher-order thinking questions decreased during both intervention units. During nonintervention instruction, classroom activities did not include many opportunities to practice higher-order thinking. Although students had more exposure to higher-order thinking questions throughout the intervention activities, the exposure was not enough to allow them to answer these types of questions correctly on the postassessment. These decreases in scores indicates either that the intervention was not effective with helping students advance these skills or that I need to spend more time going over higher-order thinking questions with my students, to give students more exposure to these types of questions. I noticed that students were not prepared to read and write these types of answers.

Unit tests were also analyzed for evidence of higher order thinking. Each unit test consisted of 30 multiple-choice questions. All questions were categorized as higher or lower order questions, according to Bloom's Taxonomy. Item analysis for each question was performed, and average scores for high, middle, and low-achieving students on those questions demonstrating higher order thinking were recorded. Average student scores on the higher order thinking questions for each unit test are shown in Table 6.

Table 6

Average Scores of Higher Order Thinking Questions on Unit Tests for High (n=20), Middle (n=22), Low-Achieving (n=15), and All Students (N=57)

Unit Data	Nonintervention Unit	Standard Deviation	Intervention Unit 1	Standard Deviation	Intervention Unit 2	Standard Deviation
Low	66.67	13.55	58.33	23.31	68.06	9.66
Middle	71.90	12.23	73.97	14.32	69.70	13.68
High	80.58	17.40	87.60	15.88	77.78	10.73
All	74.19	15.73	75.97	20.43	72.52	12.53

Table 6 shows that while low-achieving students experienced a small increase from nonintervention to intervention unit 2, scores for both middle and high-achieving students increased in intervention unit 1 and decreased in intervention unit 2. Overall, student scores declined from nonintervention to intervention unit 2 by 1.67%. One possible explanation for these decreases is that student ran out of time during POGIL activities. Many students did not have a chance to answer the extension questions at the end of these activities, preventing students from the opportunity to practice the higher order thinking skills involved in these questions. Taking more time the next day in class to address these questions would have allowed all students to practice these skills. Again, these decreases imply that students could benefit from more experience answering these difficult questions during guided-inquiry activities, and could benefit from reviewing their answers with me. Higher order thinking questions are an inherent part of POGIL activities. With more frequent use of these activities, students would have gained more experience working through these types of questions. Perhaps by experiencing a more robust use of the POGIL intervention, students would have had the opportunity to advance their higher-order thinking skills more.

While postunit assessments and unit test scores showed declines in higher order thinking skills, interviewing students showed increases in their higher order responses. During interviews, student responses were ranked as showing no conceptual understanding, basic understanding, or advanced understanding. This information was previously presented in Table 5. During intervention units, the percentage of student responses that indicated higher order thinking increased, while responses that indicated lower order thinking decreased. Even though students' test scores indicate a decline in higher order thinking, their ability to explain higher order thoughts and demonstrate higher order thinking in discussions during intervention units was apparent. Being able to discuss one's thoughts in conversation and demonstrate these skills in a testing environment are two different abilities. While students grew in one area, they need to be proficient in both. With more practice answering higher order thinking questions and writing their responses, one would hope to see an improvement in assessment scores.

Measuring the effect of guided inquiry on students' higher order thinking skills yielded mixed results. Pre and post assessment data as well as unit test scores indicated that overall, students' higher order thinking skills declined with intervention. In contrast, interview data showed that students increased their ability to verbalize higher order responses. While students may have practiced higher order thinking during discussions, they were unable to apply these skills to written assessments.

Guided-inquiry activities and labs suggest an increase in students' conceptual understanding and problem-solving skills. The guided inquiry intervention also suggests an increase in students' motivation and attitudes towards chemistry. To measure the change in student attitude and motivation, data were collected from instructor field observations, pre and postintervention student surveys, and interviews during nonintervention and intervention units.

To measure student engagement and motivation during lab activities, my co-worker and I completed student observation guides during one lab experience for each of the nonintervention and intervention units. Observations on nine student behaviors and interactions were scored based on teacher observations and follow up questions to students. Observation scores were averaged for each unit and the results of these observations are shown in Figure 3.

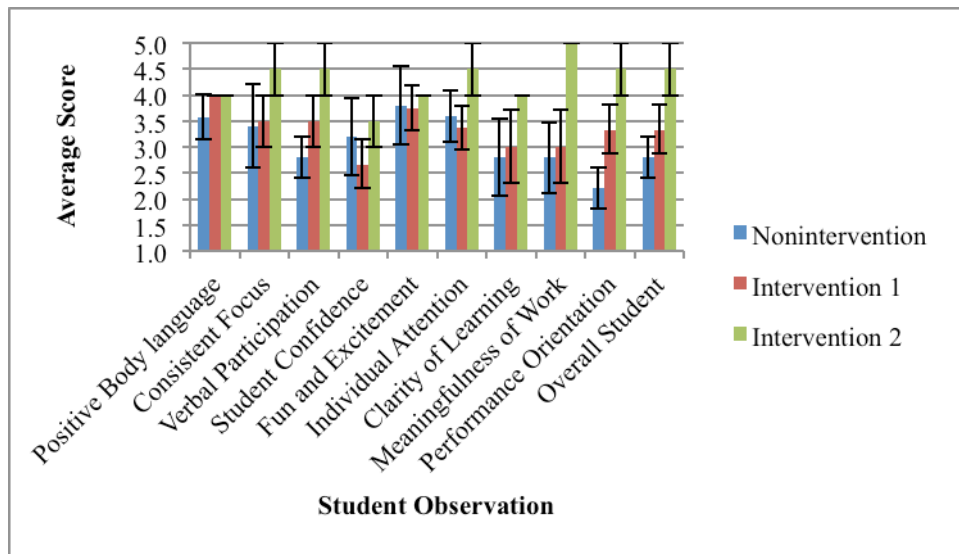


Figure 3. Comparison of nonintervention and intervention student observation scores during lab activities, ($N=57$). *Note.* Average score scale 5= Very high to 1= Very low.

Figure 3 shows that student engagement in all areas improved with guided-inquiry labs over traditional instruction. While the numerical changes were small, these numbers reflect that teachers noticed an increase in student engagement during guided inquiry labs and activities over traditional instruction. It was observed that because students had assigned roles when completing POGIL activities and guided-inquiry labs, that students stayed more focused and on task. It was also observed that the thoughtfulness and reflective nature of student dialogue improved during guided-inquiry labs. During the nonintervention lab, a lot of the discussion was procedural based: students asked low level questions of their peers such as “What do I do? How many drops

do I add? Should it turn this color?" In contrast, dialogue during guided-inquiry labs was more discussion oriented, as students asked "why" and "how" and posed possible explanations for the results they observed.

When students were asked during the nonintervention lab "what do you do when you need extra help?" all lab groups responded with "ask the teacher." During intervention labs, after students were accustomed to working in teams to solve problems, the responsibility for learning shifted to the student. Most groups then responded "we ask our group members first and try to come to agreement, then if we can't we ask the teacher." It was also observed that students could articulate the purpose of lab exercises much more thoroughly during intervention activities, whereas during nonintervention, one group admitted "I don't know what we're supposed to get out of this lab." Students also found guided-inquiry labs to be more meaningful and understood how their work would be assessed. During nonintervention, students reported that labs were "easy, and we know we did a good job if we get the right results." During intervention, students explained that guided-inquiry labs were "more challenging, and we get graded both on the correctness of our data, and how we perform our role. We get rubrics and we rate our own performance each day." Students were observed to take more ownership for their learning, as their grade depended on how well they contributed to the group's success. Students also reported that "these labs teach us concepts because we have to figure it out for ourselves; we get to decide how to set up the lab." By writing their own procedures and creating their own data tables, students found the work to be more meaningful than traditional lab activities. It should be noted that scores in all areas during intervention unit two were higher than intervention unit one, because students were still hesitant about performing their assigned roles and were becoming accustomed to the different process and expectations associated with guided-inquiry labs. By

intervention unit two, students felt increased confidence in what they were doing, and had more practice working as a team with defined roles.

The data collected from pre and postintervention surveys allowed me to measure how student's perceptions of chemistry changed after engaging in guided inquiry. In general, student responses indicated that their attitudes towards chemistry improved after experiencing guided inquiry. Students were asked to rate the statement "I look forward to coming to chemistry class." Figure 4 shows student responses to this question before and after intervention.

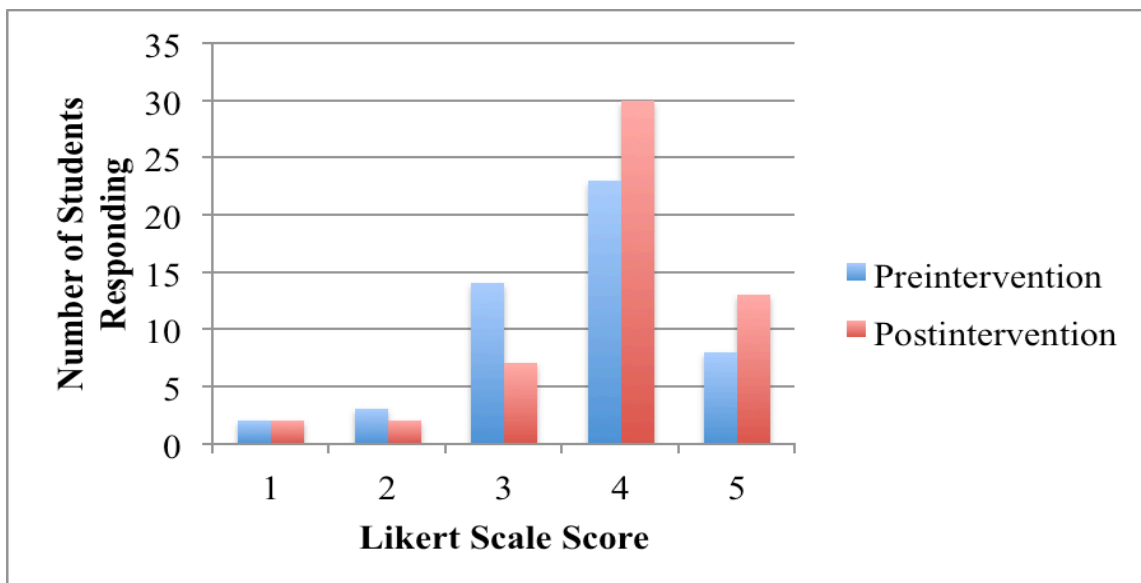


Figure 4. Student ranking for statement "I look forward to chemistry class" for all students, ($N=54$). *Note.* Likert Scale 5= I look forward to class very much to 1= I do not look forward to class.

Results in Figure 4 show that overall, students' attitudes towards attending class improved from nonintervention to intervention. Figure 4 shows a shift from responses indicating indifference to more positive responses. Students were asked to explain their rating as to why they did or did not look forward to coming to class. Responses were analyzed for common reasons and categorized into eight categories, based on key words written in the response. The results of these responses are shown in Table 7.

Table 7
Percentage of Responses for Reasons Why Students Did or Did Not Look Forward to Coming to Chemistry Class (N=57)

Reason Cited for Attitude Towards Class	Preintervention	Postintervention	Percent Change
Fun	17.2	21.3	23.8
Easy	14.1	14.8	5.0
Interesting	14.1	13.1	-7.1
Labs/Experiments	14.1	19.7	39.7
Social	9.4	9.8	4.3
Indifferent	6.3	8.2	30.2
Confusing	9.4	8.2	-12.8
Boring	15.6	4.9	-68.6

These data show that after experiencing guided inquiry, students perceived chemistry class to be more fun and less boring than during traditional instruction. During preintervention, many students cited lectures and completing worksheets as a reason why they did not look forward to class. One student wrote, “I look forward to chemistry class when we are doing fun things such as labs. When we are just taking notes the entire class time it isn't something I look forward to.” Many students also wrote that they found traditional teaching to be repetitive and un-engaging, as evidenced by the student who responded “Chemistry has gotten very redundant and I feel like all we do is balance and name”. In contrast, postintervention responses showed that student perceptions of chemistry benefitted from the hands on, active nature of guided-

inquiry instruction. Students who listed labs and experiments as a motivating reason to attend class increased from 14.1% to 19.7% after intervention, a percent change of 39.7%. One student wrote “I love this class because we are doing a lot of fun experiments” while another responded “I love coming in to do new experiments that teach us the concepts.” In addition, the number of students who responded that chemistry was boring decreased dramatically after the guided-inquiry intervention, from 15.6% to 4.9%.

Interviewing students gave more insight into how students learned from guided inquiry. When asked, “In what ways were the guided-inquiry lessons and activities effective in helping you learn?” many students responded that working together in teams increased their understanding. Regardless of ability level, students thought that working in groups and debating conflicting viewpoints helped them understand the material on a deeper level. One middle-achieving student responded “The group work helps me the best. Having more than one opinion made of all of us rethink our ideas to find out the correct answer.” Another student responded that “POGIL activities were effective because everyone in your group would talk about it and go through it together. If you didn't understand something someone would try to explain it.”

Students also found that having defined roles within the group gave them more ownership of the activity and provided a clear sense of structure to their work. One student wrote, “I liked it because everyone had a certain job to make sure got complete and it helped the group stay on task” while another student responded that “It felt like you had a responsibility. The roles were a good assessment because it reassured people that everyone needs to take part in the POGIL groups.”

While all students agreed that guided inquiry was initially more difficult than traditional instruction, they also agreed that the hands on nature of these lessons were extremely beneficial.

One student said “the labs gave us a visual representation of what we were learning in class, the hands on labs helped me learn better” while another student responded “with these labs you can actually see what was happening with everything instead of just sitting at a desk looking at words and pictures. This made it easier to understand concepts and put them to use.” In addition, a lower level student responded that guided-inquiry labs “made the [gas] laws make sense by showing us hands on how it works.” The interviews verified what the survey data showed, namely that the active learning in teams when students take ownership of their learning increased student engagement and positive attitudes toward science.

Field notes, survey and interview data all show that students had an overall positive response to guided inquiry. When asked, “On a scale from 1 to 10, please rate the following statement: "I would recommend the guided-inquiry method of teaching for next year." A positive recommendation was given by 75.9% of students. A summary of their Likert scale responses is shown in Figure 5.

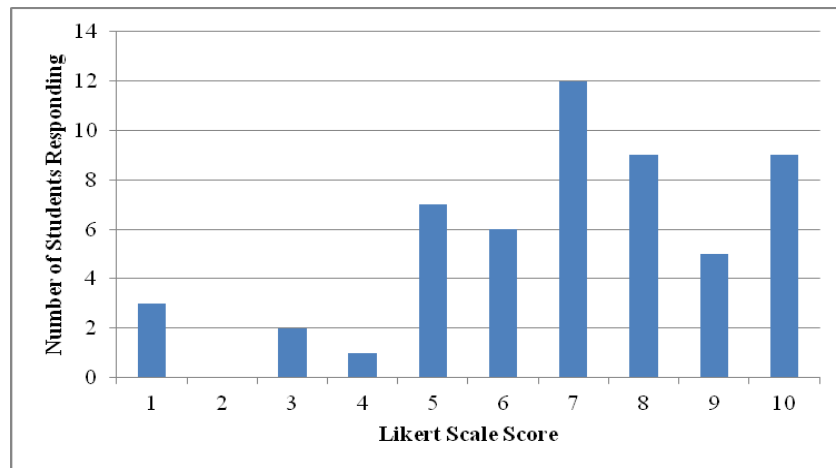


Figure 5. Postintervention guided inquiry recommendation scores given by students, ($N=54$).
Note. Likert Scale 5= I would highly recommend to 1= I would not recommend at all.

While only 5.5% of all students would not recommend guided inquiry at all, most of these students listed problems working with their assigned group or preferring to work alone as

reasons for their ranking, not actually having issue with the guided-inquiry activities themselves. When asked to explain why they would recommend the use guided inquiry in the future, students cited increased engagement, fun activities, and social interaction as reasons to continue teaching this way. One student wrote that “it makes the things [chemistry concepts] easier to understand” while another student wrote that guided inquiry was “more fun and gives you a chance to work with others.” Besides finding guided-inquiry activities to be more enjoyable than traditional instruction, students also reflected that this method taught them important academic skills. One student wrote that “I think it was good learning experience and taught me better communication skills” while another student recognized that guided inquiry “will help students become more independent.” Students benefitted from the intervention because they practiced process skills and critical thinking, were more engaged and excited, and felt they understood concepts better as a result of guided inquiry.

To measure the effect that guided-inquiry instruction had on my teaching and attitudes toward teaching, I analyzed my colleagues’ observations during nonintervention and intervention units. I also analyzed weekly journal entries I wrote during each nonintervention and intervention units. Additionally, I analyzed my responses to the Teaching Goals Inventory before and after intervention to measure how my overall goals for teaching have changed as a result of this intervention.

My colleague observed a lab activity in both the nonintervention unit and intervention unit 2. After each lab, she and I discussed the results of her observation, using the teacher observation guide (Appendix O) to guide our discussion. During the nonintervention lab, my colleague described the lesson as teacher centered, because I gave an introduction to the lab where I explained what the students needed to do and modeled how to do it, and students

performed the lab as I instructed. I closed the lesson by summarizing the key observations of the lab, while students checked their answers as I summarized results. During intervention, she described the guided-inquiry lab as student centered. I introduced the activity by simply providing the purpose for the day's lab, telling students "your goal today is to determine the relationship between pressure and volume." I then showed students the materials they had to work with, and they began to work. Students had to formulate their own hypotheses and procedures, and determine the relationship between the variables themselves. To close the lesson, I called on student groups to report out their findings, and students summarized results. I acted only as a guide to the discussion.

Another change my colleague observed between her two observations was that my conversation with students changed during the lab activities. During the nonintervention lab, she reported that much of my interaction with students was procedural based, answering clarification questions, and helping set up the lab. During the intervention lab, she reported that I asked more critical thinking questions, such as "Why do you think that is happening?" and "What can you conclude?" She noticed that I made an effort to not directly answer student questions, rather guide them to the by asking follow up questions. She commented that while my engagement with students was high in both labs, the nature of the interaction was different. Rather than providing answers as I did during nonintervention, I led students to think for themselves.

My weekly reflections demonstrated an increase in motivation as I grew more comfortable teaching with guided inquiry. During my nonintervention journal entries, my responses indicated I had a low level of energy, and also frustration that students really struggled with writing balanced equations and predicting products. My responses also showed that I was

apprehensive about starting the intervention, and as a result used a lot of preparation time to prepare for it.

During intervention unit 1, my first few reflections indicated that my motivation initially decreased using guided inquiry. I felt the first few attempts at POGIL with my students had been hectic, and that students were confused by the strategies. My journals show a period of adjustment as I learned how long POGIL activities should take, how to best conduct group check ins and mini-lessons, and how to keep all ability groups (slow and accelerated) on track. I also struggled in my new role as a facilitator. It was difficult for me not to provide immediate answers to students. As my students and I progressed using guided inquiry, my reflections indicated that my motivation increased. I wrote that I was excited to not be lecturing, and I was enthusiastic by my students' eagerness to engage in POGIL activities. Students became familiar with the assigned roles, and needed less prompting.

By intervention unit 2, my reflections indicated that my students had gained confidence with POGIL activities and took more initiative. I reflected that I became better at anticipating where students might need help during an activity, and could plan my mini-lessons more efficiently. I also observed that when students called me over to their group, they wanted to share their ideas and conclusions rather than ask me for clarification. I was impressed by the level of questioning students engaged in during group discussions. I observed that even students who never talked before in lab were participating and explaining what they knew. I wrote that I felt more excited to come to class. I knew that my instruction was more varied, which increased my energy level as well as the students' level.

Analyzing my responses to the Teaching Goals Inventory showed that my overall goals for teaching have changed as a result of using guided inquiry. The Teaching Goals Inventory

rates the importance of 52 teaching goals as essential to not applicable, and orders these goals into six different categories. Before intervention, I ranked the category of discipline-specific knowledge and skills as my highest category. This implies that before the intervention, I believed that my primary goal as a teacher was to teach students the facts and principles of chemistry. After the intervention, I instead ranked the category of higher-order thinking skills as my highest category. By reading about guided inquiry, preparing for the intervention, and finally implementing these ideas for myself, I changed my motivation for teaching. I now feel that my role as an educator is to help students develop critical thinking skills, not just learn about chemistry.

Guided inquiry has improved both my motivation as a teacher, and my goals for teaching. Colleague observations show that guided inquiry has made my instruction more student centered, and has increased the quality of interaction I have with my students. Weekly reflections indicate that my motivation increased as I became more confident in my ability to teach using guided inquiry. Finally, guided inquiry has also changed my purpose for teaching. My desire for my students is not only to learn the content of chemistry, but to become independent, critical thinkers.

INTERPRETATION AND CONCLUSION

This study suggests that guided-inquiry labs and activities increased student conceptual understanding, problem-solving skills, and motivation. Assessment data showed that all students increased their conceptual understanding, with low and middle-achieving students showing the most improvement. Assessment data also showed that low and middle-achieving students gained the most problem-solving skills during the guided-inquiry intervention. In contrast to the gains

seen in conceptual understanding and problem-solving skills, none of the achievement groups showed a measureable increase in higher order thinking skills.

Interview data suggests that low and middle-achieving students showed the most growth in both conceptual understanding and problem-solving skills. These students demonstrated an increased ability to explain their thought process while solving a problem. Additionally, these students progressed from surface level explanations of concepts to demonstrating deeper understanding during the guided-inquiry intervention. High-achieving students showed only modest growth. These results might indicate that the assessments used to measure their growth were not difficult enough. Perhaps the ceiling of the assessment may have limited the amount of growth high-achieving students were able to demonstrate. Students of all achievement levels credited guided-inquiry activities and group work with defined roles as the reason for their improved conceptual understanding and problem-solving skills.

Student engagement and motivation improved with guided inquiry. During guided-inquiry labs, students were observed to be more engaged and self reliant than during nonintervention labs. Students reported that guided-inquiry labs were both more challenging and more meaningful than traditional activities. Survey data showed that all students' motivation to attend class increased with guided-inquiry instruction. Students also perceived chemistry class to be more fun and less boring with guided-inquiry activities. Students had an overall positive response to guided inquiry, with 75.9% of students recommending that I continue teaching this way next year.

Not only was an increase in student motivation observed with guided inquiry, my motivation increased as well. As a result of teaching with guided inquiry, my instruction became

more student centered, and my purpose for teaching shifted. My purpose in the classroom is not solely to teach chemistry, but to develop independent, critical thinkers.

This study failed to show that students measurably increased their higher-order thinking abilities on unit tests. Since students did show growth on these skills during interviews, I know realize that multiple-choice questions do not measure higher order thinking well. By changing these multiple-choice questions to free response, I could have collected better data, and perhaps seen an improvement in higher-order thinking skills on unit tests. During interviews, I only categorized student responses as exhibiting basic or advanced understanding. If instead I had used a Likert scale to rate higher order thinking, I could have more accurately shown which level of Bloom's Taxonomy students had reached. Students' failure to show growth on higher-order thinking skills does not necessarily imply that the POGIL intervention failed to improve these skills; rather that the intervention needed to be more robust. By increasing the use of POGIL activities during intervention units, students would have gained more experience answering these questions. Additionally, providing increased numbers of higher-order questions throughout POGIL activities would also give students the opportunity to practice these skills more often. I should also keep a log of the higher order questions I write for activities, to ensure that they are consistently being asked. By providing students with consistent practice and feedback on their answers, students may show an increase in their higher-order thinking skills in the future.

VALUE

The goal of this project was to increase student understanding, and allow my students to become more independent, critical thinkers. This study encourages me to expand using guided inquiry in all units of chemistry by re-writing labs and activities to promote more higher-order thinking and student-directed learning. As students gain proficiency in critical thinking,

collaboration, and verbalizing their understanding, they should be able to apply these skills to all other academic areas. These problem-solving and interpersonal skills will aid students as they become contributing members of society.

My colleagues can benefit from this project by utilizing my research to begin using POGIL in their own science classrooms. I have presented my findings to my department. As a result, many teachers who desire similar improvement in student engagement and problem-solving skills have asked me for more information about implementing POGIL. I have invited other teachers to observe guided-inquiry lessons in my classroom, and these teachers are interested in trying this out in their own rooms. Ideally, my department would adopt using guided inquiry in all levels of science, from freshman biology through physics. In this way, all students would have the opportunity to build their problem-solving abilities and higher order thinking skills thorough their entire high school career. The problem-solving skills, teamwork, and assigned roles inherent in POGIL activities would lend themselves well all other subject areas.

It would be interesting to measure the effect that POGIL activities have on students' long-term memory of chemistry concepts, as well as retention of problem-solving skills. The next step of this project would be to extend POGIL activities to all units of the chemistry curriculum, documenting student growth for an entire year as opposed to just two units. These data could be compared to previous years of student achievement data, analyzing unit tests as well as standardized test scores. If guided inquiry was implemented across the science curriculum, a long-range departmental study could be completed.

Teaching with guided inquiry has shown me the value of thoroughly engaging my students. Through this intervention, I had the opportunity to know my students better in regard to

their interests and motivation. This process gave me a deeper insight into how my students learn and think. Guided inquiry has also allowed me to have conversations with my students about their learning that I have never had before. This process has also changed the way I think about teaching. My job as a teacher is not only to impart conceptual knowledge, but also to nurture my students' inquisitive nature so that they can become independent learners.

REFERENCES CITED

- Angelo, T., & Cross, K. (1993). *Classroom assessment techniques*. San Francisco, CA: Jossey Bass.
- Asay, L.D., & Orgill, M.K. (2010). Analysis of essential features of inquiry found in articles published in the science teacher, 1998-2007. *Journal of Science Teacher Education*, 21(1), 57-79.
- Barrow, L. (2006). A brief history of inquiry: From Dewey to standards. *Journal of Science Teacher Education*, 17(3), 265-278.
- Briggs, M., Long, G., & Owens, K. (2011). Qualitative assessment of inquiry-based teaching methods. *Journal of Chemical Education*, 88(8), 1034-1040.
- Buthelezi, T., Dingrando, L., Hainen, N., Wistrom, C., & Zike, D. (2008). *Chemistry: matter and change*. Columbus, OH: McGraw-Hill Companies, Inc.
- Cakir, M. (2011). Enhancing Mendelian genetics concepts using a guided computer-mediated inquiry. *Journal Of Baltic Science Education*, 10(3), 156-167.
- Cavallo, A.L., & Laubach, T.A. (2001). Students' science perceptions and enrollment decisions in differing learning cycle classrooms. *Journal of Research in Science Teaching*, 38(9), 1029-1062.
- Chatterjee, S., Williamson, V., McCann, K., & Peck M.L. (2009). Surveying students attitudes and perceptions toward guided-inquiry and open-inquiry laboratories. *Journal of Chemical Education*, 86(12), 1427-1432.
- Cheung, D. (2011). Teacher beliefs about implementing guided-inquiry laboratory experiments for secondary school chemistry. *Journal of Chemical Education*, 88(11), 1462-1468.
- Christmann, E.P. (2012). *Beyond the numbers: making sense of statistics*. Arlington, VA: National Science Teachers Association.
- Christopherson, J. (2012). S'more Chemistry. In Illinois State University's *Partnerships for Research in Science & Math Education (PRISM)*. Retrieved from <http://www.gk12.ilstu.edu/chemistry/index.asp?page=stoichiometry>
- Flinn Scientific, Inc. (2003). *Elasticity of gases activity*. Batavia, IL.
- Jones, R. (2009). *Student engagement teacher handbook*. Rexford, NY: International Center for Leadership in Education. Retrieved from <http://www.leadered.com/pdf/Student%20Engage%20handbook%20excerpt.pdf>

- Keeley, P., Eberle, F., & Dorsey, C. (2008). *Uncovering student ideas in science volume 3*. Arlington, VA: National Science Teachers Association.
- L&L Peer Mentoring Observation Form. (2012). In *Benedictine University's sample forms for teaching observation*. Retrieved from http://www.ben.edu/fac_staff/ctle/resources/sample-forms-for-teaching-observation.cfm
- Lowery, N.V. (2003). The Fourth "R": Reflection. *The Mathematics Educator*, 13(2), 23-31.
- Martin-Hansen, L. (2002). Defining inquiry. *The Science Teacher*, 69(2), 34-37.
- Mintzes, J.J., Wandersee, J.H., and Novak, J.D. (2001). Assessing understanding in biology. *Journal of Biological Education*, 35(3), 118-124.
- Mintzes, J.J., Wandersee, J.H., and Novak, J.D. (1998). *Teaching science for understanding: A human constructivist view*. San Diego, CA: Academic Press.
- Miri, B., David, B.C., & Uri, Z. (2007). Purposely teaching for the promotion of higher order thinking skills: A case of critical thinking. *Research in Science Education*, 37(4), 353-369.
- Moog, R.S. & Spencer, J.N. (2008). POGIL: an overview. *Process Oriented Inquiry Learning (POGIL)* (1-13). Washington, D.C. : American Chemical Society.
- National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, D.C.: National Academy Press.
- POGIL Project* (2012). Retrieved August 20, 2012 from <http://www.pogil.org>
- Renner, J.W., Abraham, M., & Birnie, H. (1988). The necessity of each phase of the learning cycle in teaching high school physics. *Journal of Research in Science Teaching*, 25(1), 39-58.
- Tatar, N. (2012). Inquiry-based science laboratories: An analysis of preservice teachers' beliefs about learning science through inquiry and their performances. *Journal of Baltic Science Education*, 11(3), 248-266.

APPENDICES

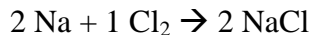
APPENDIX A

NONTREATMENT ACTIVITY: CHEMICAL DEMONSTRATIONS LIST

Five Types of Chemical Reaction Demonstrations

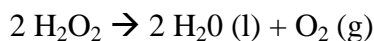
1.Synthesis : $A + B \rightarrow AB$

While there is no reaction to perform, I discuss the following equation with students:

2.Decomposition: $AB \rightarrow A + B$

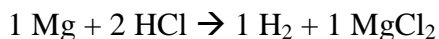
Demonstration: Elephant Toothpaste

Pour 80 mL of H_2O_2 , 40 mL of Dawn dish soap into a 1,000 mL graduated cylinder. Add drops of red and blue food coloring down the sides of the cylinder to look like toothpaste. When ready, add a small vial of concentrated KI solution. The foam rapidly forms and moves up and out through the graduated cylinder. The dishwashing detergent captures the oxygen as bubbles. This is an exothermic reaction.

3.Single Replacement: $A + BX \rightarrow AX + B$

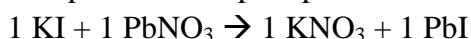
Demonstration: Barking Dog

Add a few concentrated drops of HCl with a few Mg pellets. Collect the H_2 gas with a second test tube. Light a splint insert into the top of the 2nd test tube. You should hear a whistling noise.

4.Double Replacement: $AB + CD \rightarrow AD + CB$

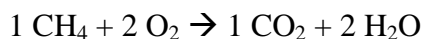
Demonstration: Golden Test Tube

Place two small test tubes with reactants side by side in a stoppered Erlenmeyer flask. Quickly invert the flask to mix reactants. Lead nitrate and potassium iodide instantly turn yellow when mixed. Be sure to point out the precipitate formed.

5.Combustion: $\text{C}_x\text{H}_y + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$

Demonstration: Methane Bubbles

Put a small amount of dawn dish soap and water into a glass bowl. Add methane gas from a gas jet using Bunsen burner tubing. When bubbles have risen, light on fire using an aim and flame.



APPENDIX B

NONTREATMENT ACTIVITY: IDENTIFYING CHEMICAL REACTION TYPES
HOMEWORK

Identifying Reaction Types WSName:

Balance the following equations:

Identify the type of reaction:

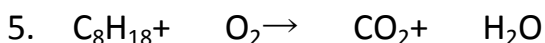
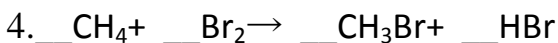
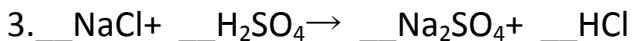
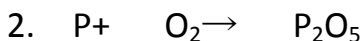
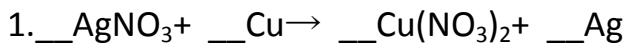
1	$\text{___ Na} + \text{___ O}_2 \rightarrow \text{___ Na}_2\text{O}$	
2	$\text{___ H}_2 + \text{___ Cl}_2 \rightarrow \text{___ HCl}$	
3	$\text{___ P} + \text{___ O}_2 \rightarrow \text{___ P}_2\text{O}_3$	
4	$\text{___ KClO}_4 \rightarrow \text{___ KCl} + \text{___ O}_2$	
5	$\text{___ NH}_3 + \text{___ H}_2\text{SO}_4 \rightarrow \text{___ (NH}_4)_2\text{SO}_4$	
6.	$\text{___ Zn} + \text{___ Pb(NO}_3)_2 \rightarrow \text{___ Zn(NO}_3)_2 + \text{___ Pb}$	
7	$\text{___ Cu} + \text{___ S} \rightarrow \text{___ Cu}_2\text{S}$	
8	$\text{___ Al} + \text{___ H}_3\text{PO}_4 \rightarrow \text{___ H}_2 + \text{___ AlPO}_4$	
9	$\text{___ NaNO}_3 \rightarrow \text{___ NaNO}_2 + \text{___ O}_2$	
10	$\text{___ Mg(ClO}_3)_2 \rightarrow \text{___ MgCl}_2 + \text{___ O}_2$	
11	$\text{___ H}_2\text{O}_2 \rightarrow \text{___ H}_2\text{O} + \text{___ O}_2$	
12	$\text{___ BaO}_2 \rightarrow \text{___ BaO} + \text{___ O}_2$	
13	$\text{___ H}_2\text{CO}_3 \rightarrow \text{___ H}_2\text{O} + \text{___ O}_2$	
14	$\text{___ Al} + \text{___ Cl}_2 \rightarrow \text{___ AlCl}_3$	
15	$\text{___ P} + \text{___ O}_2 \rightarrow \text{___ P}_2\text{O}_5$	
16	$\text{___ NH}_4\text{NO}_2 \rightarrow \text{___ N}_2 + \text{___ H}_2\text{O}$	
17	$\text{___ H}_2 + \text{___ N}_2 \rightarrow \text{___ NH}_3$	
18	$\text{___ Cl}_2 + \text{___ KBr} \rightarrow \text{___ Br}_2 + \text{___ KCl}$	
19	$\text{___ P} + \text{___ I}_2 \rightarrow \text{___ PI}_3$	

APPENDIX C

NONTREATMENT UNIT: CHEMICAL REACTION UNIT QUIZZES

Chemistry S Unit 9 Name: _____

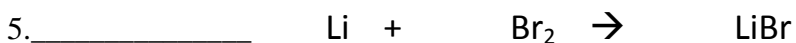
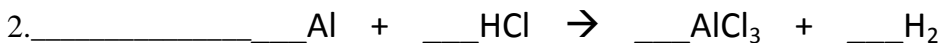
Quiz: Balancing Equations



Chemistry S Unit 9 Name: _____

Quiz: Identifying Reaction Types

For each equation, balance the equation and state the reaction type.



Chemistry S Unit 9 Name: _____

Quiz: Predicting Products



APPENDIX D

NONTREATMENT UNIT: SINGLE REPLACEMENT LAB

The following is a summary of the Single Replacement Lab. In this lab, students create their own activity series for hydrogen, copper, magnesium, and zinc.

Objectives:

To observe whether metals react with various compounds.

To develop an activity series for the metals tested.

Procedure: Students will perform the following reactions in a spot plate:

1. Copper metal with HCl, CuCl₂, MgCl₂, and ZnCl₂.
2. Magnesium metal with HCl, CuCl₂, MgCl₂, and ZnCl₂.
3. Zinc Metal with HCl, CuCl₂, MgCl₂, and ZnCl₂.

Data and Observations:

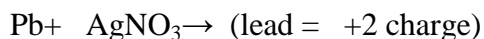
Metals	HCl	CuCl ₂	MgCl ₂	ZnCl ₂
Cu				
Mg				
Zn				

Data Analysis:

1. Which of the three metals that you tested reacted with the most compounds?
2. Which metal reacted with the fewest compounds?
3. Describe what happened in the reactions you observed.

4. List the three metals you tested from the most reactive to the least reactive.
1. most reactive
 - 2.
 3. least reactive
- ↓
5. Which of the three metals that you tested were able to replace hydrogen in HCl?
6. Where would hydrogen, as in an acid, be placed in the three metal activity series you listed?
7. Do your experimental results agree with the activity series in the textbook? Explain possible reasons for disagreement
8. Use the activity series to predict the products of these single replacement reactions.

Don't forget to balance the equations!



Conclusion:

Write a paragraph summarizing what happened in the experiment. Be sure to restate the purpose of the lab. Summarize the results of the lab, and include how two possible sources of error could have effected your data. Use terminology from Chapter 9, which includes the following words:

activity series, metal, reactivity, single replacement, element, compound

This lab was developed from McGraw-Hill's *Chemistry Matter and Change Laboratory Manual*, copyright 2008.

APPENDIX E

NONTREATMENT UNIT: FIVE TYPES OF REACTIONS LAB

The following is a summary of the Five Types of Chemical Reactions Lab. In this lab, students are introduced to the following reaction types: combination reactions, decomposition reactions, single replacement reactions, double replacement reactions, and combustion reactions.

Objectives:

To observe chemical reactions in order to determine the reaction type.

To identify the products of each reaction and balance the chemical equation.

Procedure: Students will perform the following reactions:

1. Iron metal and copper (II) sulfate solution
2. Lead (II) nitrate and potassium iodide solutions.
3. Magnesium metal and hydrochloric acid.
4. Action of heat on hydrogen peroxide.

Data and Observations:

Reaction	Observations	Reaction Type
Fe and CuSO_4 (Fe has a +2 charge)		
$\text{Pb}(\text{NO}_3)_2$ and KI		
Mg and HCl		
H_2O_2 and heat		

Data Analysis:

Predict products and write a balanced equation for each reaction observed in the procedure.

Conclusion:

Write a paragraph summarizing what happened in the experiment. Be sure to restate the purpose of the lab. Use terminology from Chapter 9, which includes the following words:

**five reaction types, single replacement reactions, double replacement reactions
combination reactions, decomposition reactions, combustion reactions**

This lab was developed from McGraw-Hill's *Chemistry Matter and Change Laboratory Manual*, copyright 2008.

APPENDIX F

TREATMENT UNIT I: MUDDIEST POINT PROBE FOR CLASSIFYING REACTIONS

Exit Slip-The Muddiest Point Name: _____

On a scale from 1 (I don't understand at all) to 10 (I understand perfectly!) Rate your level of understanding of today's lesson:

1 2 3 4 5 6 7 8 9 10

Explain your rating:

Take a minute to think about today's lesson. What did you find was the least clear or the most confusing about classifying reaction types? Write your "Muddiest Point" here:

APPENDIX G

TREATMENT UNIT I: SMORES EXPLORATION ACTIVITY

S'more Exploration Activity

This activity introduces student to stoichiometry using a recipe for making a smore. After completing an initial set of problems, students are introduced to the vocabulary of limiting reactant and excess reactant. After students complete all problems, they check their answers with their teacher and proceed to a lab station to make a s'more.

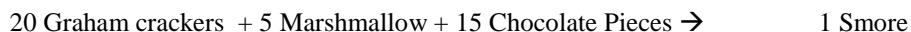
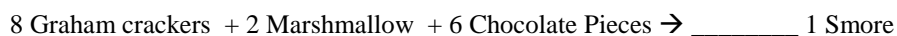
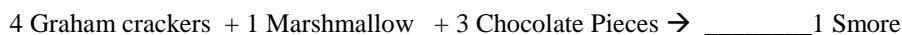
The balanced equation for these problems is as follows:



A selection of questions is provided below:

1. Notice that to make this recipe you have 8 pieces (reactant) to the left of the arrow and 1 piece (product) to the right. This is supposed to represent a balanced equation, so how can $8 = 1$? Explain.
2. How many of each ingredient will be needed if a class of 25 students each wants to make a s'more? Explain using a chemical equation.
3. If I have 15 graham crackers, how many marshmallows and chocolate pieces will I need to make Smores? How many S'mores can I make?
- 4a. You decide to make S'mores with 90 chocolate pieces. How much of each other ingredient do you need? How many S'mores can you make?
- 4b. Oops! You only have 30 graham crackers. How does this change the number of S'mores you can make?

5. How many Smores can you make from these combinations?



6. When a reactant is left over, it is what we call "in excess" and those that are used up and limit how much can be made and are called **limiting reactants**. The maximum number of S'mores you could make is called the **theoretical yield**. For example, if you had 18 graham crackers, 9 marshmallows, and 22 chocolate pieces, determine the following:

Limiting Reactants:

Excess Reactants:

Theoretical Yield:

This lab was adapted from Illinois State University's *S'more Chemistry*, copyright 2012

APPENDIX H

TREATMENT UNIT II: GAS LAW EXPLORATION PROBE

Balloons in February

It is February in Chicago. Jackie went to the store to buy a balloon for her sister's birthday. The clerk at the store filled the balloon with air and sealed the balloon so no air could escape. Jackie took the balloon out of the warm store and walked home in the cold. Before she went in her house, she noticed that while no air had escaped from the balloon, the balloon had shrunk.

Jackie wondered if the mass of the balloon changed as well. With which one of the following statements about the mass of the balloon would you agree and explain your reasoning below.

_____ The mass of the warm balloon is greater than the mass of the cold balloon.

_____ The mass of the warm balloon is less than the mass of the warm balloon.

_____ The mass of the warm balloon is the same as the mass of the cold balloon.

Explanation:

This formative assessment probe was developed from National Science Teachers Association's *Uncovering Student Ideas in Science Volume 3*, copyright 2008.

APPENDIX I

TREATMENT UNIT II: BOYLES LAW GUIDED INQUIRY LAB

Boyle's Law Guided-Inquiry LabName: _____

Hour: _____

Problem: What is the relationship between the pressure and volume of a gas?

Equipment: a plastic syringe, 10 books, ringstand, test tube clamp.

Procedure:

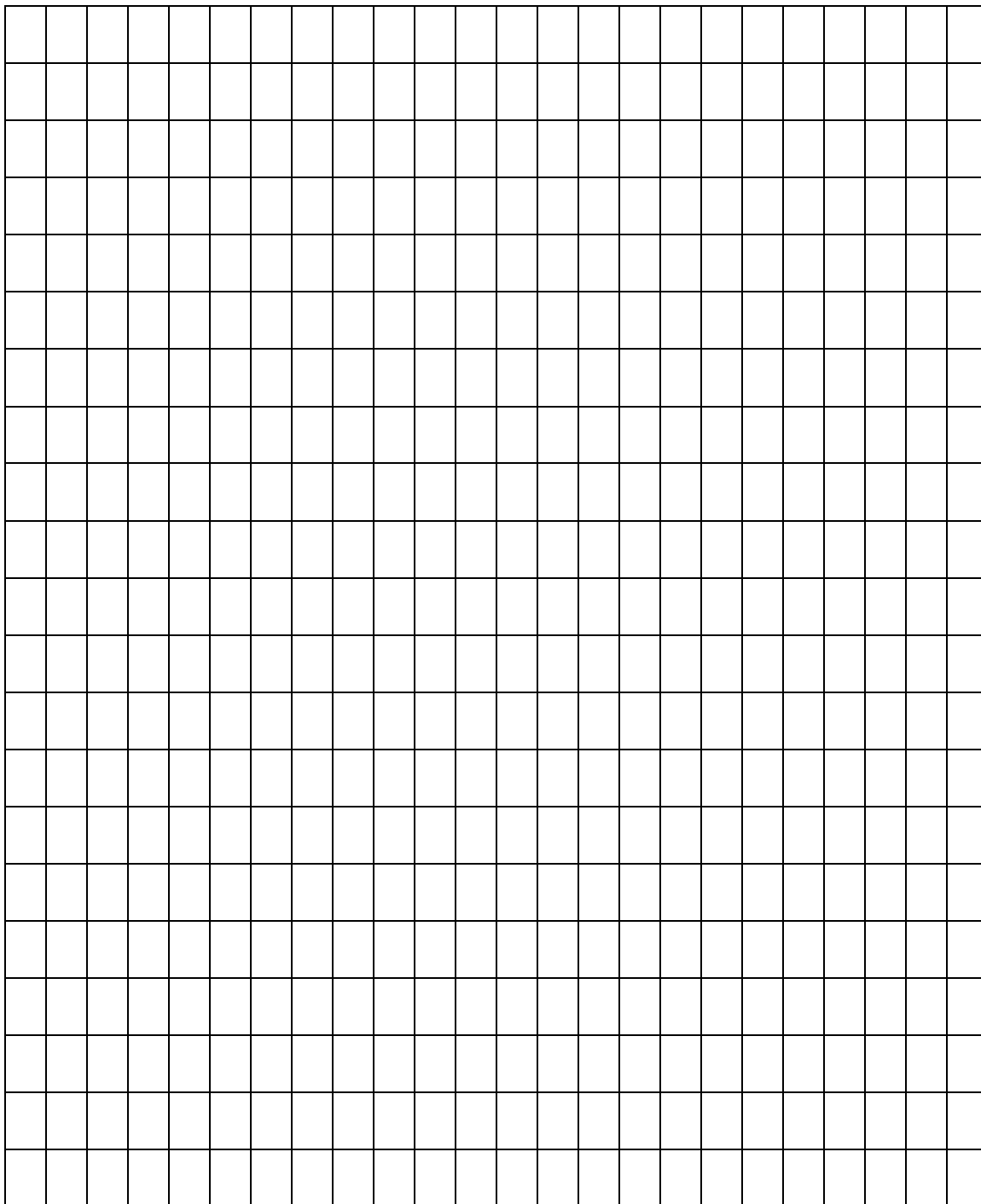
1. Remove cap from the syringe. Adjust the volume to 60 mL. Replace the cap.
2. Place the platform holding the syringe flat on your ring stand and clamp into place. Check the volume reading on the syringe. If the volume is not exactly 60 ml, remove the cap and adjust the piston.
3. Place one book on the platform connected to the top of the piston. Be sure to hold the sides of the book for balance. Do NOT support the weight of the book. Record the new volume in data table 1.
4. Continue to add books to the piston, one at a time, recording the volume after each book is added.

Data Table: In the space provided, create a data table that records the pressure and volume. Be sure to label your data table.

The independent variable is _____. The dependent variable is _____.
_____ and _____ were held constant during the collecting of
data. When plotting a graph, _____ will go on the x-axis and _____ will
go on the y-axis.

Data Analysis:

1. Plot the points on a graph showing the relationship between volume and pressure. Be sure to use the TASTE method of graphing.
2. Draw a line of best fit. The line may not go through the origin.



Conclusion Questions:

1. What kind of relationship does the graph show? _____
2. Using your graph, predict what would happen to the pressure of the gas if the volume was cut from 32 mL to 16 mL.
3. Using your graph, predict what would happen to the volume of the gas if the pressure was doubled from 7 books to 14 books.
4. Using what you learned in this lab, put pressure and volume into a mathematical equation showing their relationship and explain in words what is happening.

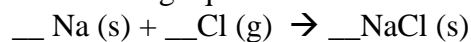
This lab was developed from Flinn Scientific's *Elasticity of Gases Activity*, copyright 2003.

APPENDIX J

STUDENT PRE AND POSTASSESSMENT QUESTIONS

Nontreatment Pre and Postunit Assessment Questions: Chemical Reactions

For questions 1-4, use the following equation:



- List the reactants in this equation.
- List the products in this equation.
- State whether or not this equation is balanced. If not, balance the equation.
- Diagram and explain the parts of a chemical reaction.
- Identify how you can tell if a chemical reaction is occurring.
- Discuss why equations must be balanced.
- Develop a balanced equation to represent the following model of chemical reaction:



- Evaluate how the following factors might influence the rate of a reaction:
 - Activation Energy
 - Effect of Temperature
 - Catalysts
 - Inhibitors

Treatment Unit 1 Pre and Postunit Assessment Questions: Stoichiometry

- Define what determines the amount of product made during a chemical reaction.
- Identify how you can tell when a chemical reaction stops and explain why it stops.
- A bag of brownie mix makes 15 brownies. If 1 egg and 1/3 cup of oil are needed to make a bag of brownie mix, Calculate how brownies can made with 4 eggs and 1 cup of oil. Explain how you got your answer.

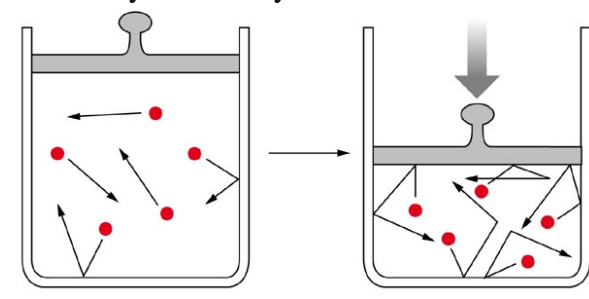
Use the following equation to answer question 4 and 5:



- If 2 moles of S and 2 moles of O₂ react, how many moles of SO₃ would be produced?
- If 32 grams of sulfur and 32 grams of oxygen are combined, calculate how many grams of sulfur trioxide can be produced. Be sure to explain your answer.
- Explain and defend the following statement: In a chemical reaction, nothing is created or destroyed.

Treatment Unit 2 Pre and Postunit Assessment Questions: Gas Laws

1. Define the terms pressure, volume and temperature. What units do we use for each of these measurements?
2. Identify the relationship between pressure and volume. What happens to pressure inside a balloon if the balloon gets larger? Draw a picture if you can and explain your answer.
3. Identify the relationship between volume and temperature. What happens to the volume of a balloon if it gets very warm? Does the mass of the balloon change?
4. Sketch a picture to demonstrate why gases are easier to compress than liquids or solids. Explain your drawings.
5. This picture shows two containers holding gas molecules. Compare and contrast these pictures using as many vocabulary words as you can.



6. Develop an experiment to test what happens to the pressure inside a container if more gas is added to the container. Generate a hypothesis, a procedure, and predict the results for your experiment.

APPENDIX K

PRE AND POSTTREATMENT STUDENT SURVEY QUESTIONS

Student survey questions were designed to evaluate student perception of understanding, higher order thinking skills, problem-solving skills, and motivation. Surveys were given before and after the treatment. Questions 6-14 were omitted from the pretreatment survey.

This survey is for the purpose of gaining student feedback in chemistry. This survey is completely voluntary. Your participation/nonparticipation in this survey will not affect your grade or class standing.

1. On a scale from 1 to 5, please rate the following statement: I look forward to chemistry class.
I do not look forward to class I look forward to class very much
1 2 3 4 5
2. On a scale from 1 to 5, please rate how difficult you found this unit to be:
Very easy Very Difficult
1 2 3 4 5
Explain:
3. On a scale from 1 to 5, please rate how well you understand the concepts in this unit's material.
I don't understand it at all I understand it completely
1 2 3 4 5
Explain:
4. What activities during this unit have been the most helpful to you? Explain
5. What activities during this unit have been the least helpful to you? Explain
6. Has doing guided inquiry changed the way you feel about chemistry? Please rate your response on a scale from 1 to 5:
Changed my feelings Changed my feelings
very little very much
1 2 3 4 5
Explain:
7. In what ways were the guided inquiry lessons and activities effective in helping you learn?
Explain.
8. Do you prefer inquiry learning or traditional learning? Explain why you feel this way:
9. Which is easier, inquiry learning or traditional learning? Explain why you feel this way:
10. How did you like working in groups when you had a defined role? Explain why you feel this way.
11. How did you like doing Explore activities before the teacher explained the concept? Explain why you feel this way.

12. How did using online simulations help you learn about chemistry? Explain why you feel this way.
13. How did writing your own procedures and making your own data tables during labs improve your problem-solving skills? Explain why you feel this way.
14. Is there anything else you would like to say about guided inquiry? If so, please write your comments here.

APPENDIX L

PRE AND POSTUNIT STUDENT CONCEPT INTERVIEW QUESTIONS

Student concept interviews were conducted with student generated preunit and postunit concept maps. Student interviews focused on content understanding, problem solving, and higher-order thinking. The following questions served as a guide for students during the interview that was conducted in a discussion format where students shared their understanding and motivation verbally.

Nontreatment Unit Interview: Chemical Reactions:

1. Make a concept map for me using the words reactants, products, chemical reaction, synthesis, decomposition, double replacement, single replacement, combustion. You may add extra words if you would like. As you make the map, explain how you arranged the words. Read the map to me when it is complete.
2. Identify the parts of a chemical reaction. Draw a picture to illustrate your points.
3. Explain why it is important to balance chemical reactions. What did you learn about chemical reactions?
4. Predict the products and balance the reaction between sodium metal and chlorine gas. Explain how you came up this answer.
5. What activities helped you learn these relationships the best?

Treatment Unit I Interview: Stoichiometry:

1. Make a concept map for me using the words stoichiometry, reactant, product, limiting, excess, coefficient, subscripts, conservation of mass, actual yield, theoretical yield percent yield. You may add extra words if you would like. As you make the map, explain how you arranged the words. Read the map to me when it is complete.
2. Explain why we do stoichiometry in chemistry. What can you tell me about it?
3. Given the reaction:

$$2 \text{ZnS (s)} + 3 \text{O}_2 \text{ (g)} \rightarrow 2 \text{ZnO (s)} + 2 \text{SO}_2 \text{ (g)}$$
 If you have 100 g of zinc sulfide, (ZnS) and 100 g of oxygen (O₂), explain which reactant is limiting and give reasons to support your answer.
 Now that you determined the limiting reactant, calculate how many grams of zinc oxide (ZnO) will be produced.
6. What activities helped you learn these relationships the best?

Treatment Unit II Interview: Gas Laws:

1. Make a concept map for me using the words pressure, volume, temperature, number of moles of gas, Kelvin, atmosphere, liters, size of container. You may add extra words if you would like. As you make the map, explain how you arranged the words. Read the map to me when it is complete.
2. Describe all the factors that could cause an increase in the pressure of a contained gas. Explain.
3. Explain the relationships between pressure, volume and temperatures of gases.
4. What activities helped you learn these relationships the best?

APPENDIX M

PRE AND POSTTREATMENT STUDENT NONCONCEPT INTERVIEW QUESTIONS

Student nonconcept interviews were conducted pre and posttreatment. Student interviews focused on student motivation. The following questions served as a guide for students during the interview that was conducted in a discussion format where students shared their understanding and motivation verbally.

Pretreatment Questions:

- 1.How did learning activities this semester affect your ability to problem solve? Explain.
- 2.How did learning activities this semester affect your ability to analyze data and communicate results? Explain.
- 3.How do you prefer to learn? What activities help you learn the best?
- 4.What motivates you to do well in Chemistry? Explain
- 5.Is there anything else you would like me to know, or any other question you think I should have asked?

Posttreatment Questions:

- 1.How do guided-inquiry activities affect your ability to problem solve? Explain.
- 2.How do guided-inquiry activities affect your ability to analyze data? Explain.
- 3.How does doing Explore activities first and hearing explanations later help you to understand concepts? Explain.
- 4.How does working in groups and reporting out affect your ability to communicate results? Explain.
- 5.In what ways is learning with guided inquiry different than learning in other ways? Explain
- 6.Was one or more methods of learning best for you? Yes or No. Which one(s)? Please explain.
- 7.Do you prefer guided inquiry to traditional learning? Please explain.
- 8.Percentage question to help with #7- I would recommend this method of teaching next year
- 9.What motivates you to do well in Chemistry? Explain
- 10.Is there anything else you would like me to know, or any other question you think I should have asked?

APPENDIX N

STUDENT OBSERVATION GUIDE

Student Observation Guide

A high, middle, and low-achieving student were selected to be observed during a lesson. Students were tracked separately, and data was gathered on each. Students were observed during the same phase of the class and with a similar activity.

Observations on ten different student behaviors during traditional labs, guided inquiry labs and POGIL activities were made. These observations included: positive body language, focus, participation, confidence, engagement, understanding, meaningfulness of work, and overall student engagement. These observations were measured using a Likert scale from 1-5. The following shows a summary of the form:

Is this student a high, middle, or low-achieving student? (Circle one)

Identify the phase of the class: beginning, middle or end. (Circle one)

What is the class activity? _____ **Date** _____

Observations: Very High High Medium Low Very Low

54321

Comments:

This guide was adapted from the International Center for Leadership in Education's *Student Engagement Teacher Handbook*, copyright 2009.

APPENDIX O

TEACHER OBSERVATION GUIDE

Teacher Observation Guide

Class Observed: _____ Date and Time of Class: _____

Phase of the class: _____

To be completed by the faculty member being observed:

1. The goal(s) or outcome(s) I have in mind for my students during this class session is:

2. During this class session, I would like the observer to pay particular attention to, and give me feedback on the following:

To be completed by the observer:

1. Describe what happened in this class session. Would you describe the lesson as mostly teacher-centered or student centered?

2. List instructor activities:

3. What teaching methods did you observe?

4. How effective were these activities and methods in achieving the goal or student outcome that the faculty member had set out for this class session? Explain.

5. Describe teacher movement through the room.

6. How well did the teacher act as a leader, to determine objectives, define expectations, and establish organization for the lesson?

7. How well did the teacher circulate through the class to monitor and assess individual and team performance?

8. How well did the teacher facilitate the lesson, by asking critical thinking questions to help teams understand and help them improve?

9. How well did the teacher provide closure to the lesson by asking team members to report answers, summarize findings, explain strategies, actions, and strategies of the team?

10. How were students grouped during the lesson? How did the teacher interact with groups?

11. Comment on teacher-student interaction and engagement during the lesson:

12. How would you describe the teacher's motivation throughout the lesson?

13. What suggestions do you have for the faculty member you observed in terms of expansion of particularly effective teaching strategies, improvement of teaching strategies that didn't work well, solving problems you observed, etc.?

14. Other comments or observations:

This form was adapted from Benedictine University's *Sample Forms for Teaching Observation*, copyright 2012.

APPENDIX P

JOURNAL PROMPTS FOR TEACHER REFLECTION

Questions For Teacher Reflection

Open-ended questions for reflection:

What did the class do today/ this week?

What did I expect to happen this week?

What actually happened?

What did I learn?

What is going well with my treatment unit? What is still difficult?

What did you learn about science, about teaching, about students and about yourself?

Questions for an individual lesson:

What were the process goals and content goals of the lesson?

How well did I act as a leader for the lesson: determining objectives, defining expected behaviors, establishing organization for the lesson?

How well did I monitor and assess individual and team performance?

How well did I facilitate group learning?

What sorts of critical thinking questions did I ask groups to help further their learning?

How well did I provide closure to the lecture by asking teams to report out, summarize main points, and explain strategies and results?

What questions did student ask, how did I respond, and why were they asked?

What motivated student learning the most and why?

What did I learn about students' prior understanding and approaches to POGIL?

What types of questioning did I use? Explain.

How did I assess student learning and the success of the lesson?

What would I do differently? How and Why?

These journal prompts were adapted from questions in Norene Vail Lowery's *The Fourth "R": Reflection*, copyright 2003.

APPENDIX Q

SUMMARY OF TEACHING GOALS INVENTORY

The Teaching Goals Inventory (Angelo and Cross, 1993) is a self assessment technique to help teachers become more aware of what they want to accomplish in their class and help them assess how well they are achieving their teaching and learning goals. There are 52 goals listed in the inventory. Teachers are asked to assess each goal's importance to what they deliberately aim to have students accomplish, rather than the goal's general worthiness.

For each goal, one needs to choose one response on the 1 to 5 rating scale. Each goal can be rated as:

- 5: Essential: a goal you always/ nearly always try to achieve
- 4: Very important: a goal you often try to achieve
- 3: Important: a goal you sometimes try to achieve
- 2: Unimportant: a goal you rarely try to achieve
- 1: Not Applicable: a goal you never try to achieve

After rating all 52 goals, teachers count up how many goals they rated as "essential". Then teachers tally how many essential goals they had in each of the six clusters: higher order thinking skills, basic academic success skills, discipline-specific knowledge and skills, liberal arts and academic values, work and career preparation, and personal development.

From these tallies, teachers can compute their cluster scores to see which clusters are most important to their teaching goals.

This inventory was referenced from Angelo and Cross' *Classroom Assessment Techniques*, copyright 1993.

APPENDIX R

PROJECT IMPLEMENTATION TIMELINE

Project Timeline

January 24- Nontreatment preunit Assessment

Started nontreatment concept interviews January 25- Direct instruction Balancing Chemical Reactions

January 29- Direct instruction 5 Types of Reactions with Demonstrations

January 30- Teach Word Equations

January 31- Quiz: Balancing Equations, Direct Instruction Predicting Products

February 1- Single Replacement Reaction Lab

1st Observation by colleague

February 4- Quiz: Types of Reactions, More Predicting Products: Station Activity

February 5- Net Ionic Equations, Solubility chart

February 6- More Net Ionic Equations

February 8- Five Types of Reactions Lab

1st Student observation by me

Collect Student Surveys

February 11- Nontreatment postunit assessment

February 13-Started nontreatment postunit concept interviews.

February 15- Stoichiometry Treatment Unit 1 preunit assessment. Start direct instruction Mole Conversions Review

February 19 POGIL instruction mole to mole conversions

February 20- direct instruction mass to mass conversions

February 22-Smores Exploration Activity

2nd student observation by me

February 25- pHet simulation *Balancing Reactions* and *Reactants, Products, and Leftovers*

February 26-Mini lesson limiting reactant problems, more practice station activity

February 28- Percent Yield Guided-inquiry activity

March 5- Limiting Reactant Quiz, Percent Yield lab (non-inquiry)

March 6- Stoichiometry Article Discussion

March 7- Stoichiometry Treatment Unit 1 postunit assessment

Started Treatment Unit 1 postunit concept interviews

March 11- Gas Law Treatment Unit 2 preunit assessment. Balloon Exploration Probe, Started direct instruction Gases and Kelvin Temperature

March 12- Boyles Law Guided-inquiry Activity

2nd Observation by colleague

March 13- Charles' law Guided-inquiry Activity

3rd student observation by me

March 14- Review Boyle's and Charles' laws, Lussac's law pHet simulation activity

March 15- Combined gas law direct instruction

March 18- Ideal gas law pHet simulation activity

March 19- Collapsing Can Guided-inquiry Activity

March 20- Report Out Collapsing Can

March 21- Posttreatment survey, posttreatment nonconcept interview

March 22- Gas Law Treatment Unit 2 postunit assessment

Started Treatment Unit 2 postunit concept interviews