# EMPHASIZING THE PROCESS OF SCIENCE USING DEMONSTRATIONS IN CONCEPTUAL CHEMISTRY

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Biological Science – Interdepartmental – Master of Science

2015

ABSTRACT

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The purpose of this project was to teach students a method for employing the process of science in a conceptual chemistry classroom when observing a demonstration of a discrepant event. Students observed six demonstrations throughout a trimester study of chemistry and responded to each demonstration by asking as many questions as they could think of, choosing one testable question to answer by making as many hypotheses as possible, and choosing one hypothesis to make predictions about observed results of this hypothesis when tested. Students were evaluated on their curiosity, confidence, knowledge of the process of science, and knowledge of the nature of science before and after the six demonstrations. Many students showed improvement in using or mastery of the process of science within the context of conceptual chemistry after six intensive experiences with it. Results of the study also showed students gained confidence in their scientific abilities after completing one trimester of conceptual chemistry. Curiosity and knowledge of the nature of science did not show statistically significant improvement according to the assessment tool. This may have been due to the scope of the demonstration and response activities, which focused on the process of science methodology instead of knowledge of the nature of science or the constraints of the assessment tool.

## ACKNOWLEDGEMENTS

I would like to dedicate this work to Libby Lutz, my daughter, who was there through every part of the master’s process with me. She was in the womb for the ecology summer and thought of fondly throughout the first two summers of her life as I spent time away from her to complete the rest of the course work. I also want to thank my husband Nate for his support through this degree program. He has freely given his time and energy to care for our child while I was away working on this degree and it could not have been accomplished without his sacrifice.

I would like to thank my mother for her professional feedback regarding the introduction of the thesis as well as the inspiration she is to me. Although I wasn’t alive to witness her dedication, as well as my father’s, to their master’s degrees, I was old enough to remember all the hours she spent working on her doctoral dissertation. Her passion for higher learning and ambition for graduate degree achievement has set for me a self-expectation to work toward this degree even if not a requirement of my profession, but instead because of the joy that learning brings and the feeling of accomplishment of working toward a goal and achieving it.

I would also like to thank my instructors in the master’s program: Merle Heidemann and Charles Elzinga. Both of whom were highly inspirational and made the program one of incredible value to me personally as well as professionally. I want to thank Merle for reading all my Frontiers papers and my thesis and offering thoughtful and constructive feedback on each work. And for her use of the problem-based learning model which increased my understanding of genetics, epigenetics, immune system function, and many other cellular processes. I want to thank Chuck for sharing with us his passion for ecology and philosophy of ecology education. The summer we spent at Kellogg Biological Station was so memorable and enjoyable; it will stay with me always.

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## INTRODUCTION

This study explored the use of demonstrations as a mode to teach the process of science in a conceptual chemistry classroom. Therefore, two bodies of research informed the direction of this study: research on the use of demonstrations in the science classroom and research on the teaching of the process of science. This study also sought to determine whether teaching the process of science through demonstrations would increase a student's understanding of the nature of science, his/her curiosity regarding observed discrepancies, as well as confidence in his or her scientific abilities.

## THEORETICAL FRAMEWORK

### Student Understanding of the Process of Science and the Nature of Science

According to a 2012 study by Vazquez-Alonso, García-Carmona, Manassero-Mas & Bennàssar-Roig (2012), students do not have a clear understanding of the distinction among scientific laws, theories, or hypotheses. By teaching the differences between these categories, students may be able to appreciate how tentative conclusions from a hypothesis can over time, with myriad amounts of accumulated evidence, be considered less provisional and instead more certain. The same study asserted that, teachers themselves do not fully accept the tentative nature of conclusions reached by the scientific community and therefore cannot adequately teach this to their students. Matson (2012) provided a resource to his students and colleagues on his website to teach the distinction between theory and law. A scientific theory is used to explain how nature works and a scientific law is used to state what nature does under certain conditions. He explained that there is no hierarchy for theories and laws (i.e. theories do not become laws over time). Teaching this difference was important for students to conceptualize the nature of scientific knowledge.

Teachers want students to act as scientists and question many ideas, but they also do not want to open Pandora's box and have students question widely-accepted principles in science which would hinder their understanding of the topic at hand (Kang & Wallace 2005). However, students need to see this uncertainty as a valuable part of the scientific process (Kirch & Siry 2012) and to be reflective on how scientists think as well, questioning their environment, looking at observations critically, and challenging assumptions.

Students must come to understand the tentative nature of scientific knowledge and the processes and experimentation that resulted in that knowledge (Duschl 1988). If too much emphasis is placed on correct answers and high grades, students will miss out on the major purpose of science, which is to find things out (AAAS 1989). The scientific process is highly recursive, requiring a constant return to asking questions, generating predictions, testing hypotheses, discussing with peers and colleagues, and refining conclusions (e.g. Salter & Atkins 2014, Fives, Huebner, Birnbaum & Nicolich 2014). Students must also be given opportunities to collaborate with peers to discuss uncertainties, curiosities, questions, hypotheses, and predictions in order for them to see the importance of the same collaboration occurring within the scientific community (AAAS 1989). This will advance their scientific reasoning and communication skills.

The methods used in this study of analyzing observations derived from demonstrations are designed to increase scientific reasoning and an understanding of the process of science as well as the nature of science. In order for students to gain understanding of the nature of science, its character must be explicitly taught. The difference between observation and inference, theory and law, the tentative nature of scientific knowledge, and role of creativity in science will not be acquired by students through participation in common lab activities as is assumed by many if not most practicing teachers (Abd-El-Khalik, Bell & Lederman 1997).

When students come to appreciate the nature of science, their scientific literacy will increase as well (Fives et al 2014). Even if students are not bound for a science-centered profession, scientific literacy, as it applies to reasoning and hypothesis testing, is important for all members of society (Deming, McDonnell & Malone 2012). According to Fives, et al. (2014) "a scientifically literate person, at the very least, must be able to determine whether and how science can be used to address questions in daily life." Feinstein (2011) describes the science literacy of the ideal citizen as one of the "competent outsider," a person who considers him or herself outside of science but can reach into science when it becomes relevant to his or her interest or needs. He argues that people will take on the role of competent outsider only after realizing the relevance of science to their daily lives or deepest concerns and interests. A goal of education is to help students reach this conclusion through practice with relevant, interest-generating topics in science class. A scientifically literate person is critical of scientific claims and will think to ask, "Are these details verifiable?" when presented with a claim made in the news or by people with whom they associate. Students need more than just scientific knowledge to be scientifically literate, they must have had the desire and capability to engage in scientific activities and apply scientific knowledge to their daily lives (Fives et al. 2014).

This is in contrast to what Feinstein (2011) characterizes as the "marginal insider," a scientifically illiterate person, someone with a limited understanding of science such that he or she viewed knowledge possessed as irrelevant to any situation outside of a science lab or classroom. Marginal insiders were less interested in science and less likely to seek out scientific information to solve a problem than a competent outsider.

According to Talanquer (2013), the way to build knowledge and thinking skills is to engage students in the process of "asking relevant questions and exploring different ways of pursuing them." Lawson (1993) in the Handbook of Research on Science Teaching and Learning Project proposes, "[i]f materials are well chosen, questions are posed, and students are prompted to think through data and problems, much can be done to encourage the acquisition of more adaptive mental structure." (p.140)

Students must be encouraged and taught to accept the nature of scientific knowledge, to build an understanding of the tentative nature of ideas and the necessity of collaborating with peers when working to resolve uncertainty by gathering data through hypothesis testing as scientists do. Even students who consider themselves science-outsiders benefit from classroom opportunities such as this, which improved scientific literacy (Feinstein 2011) and increased student confidence in their scientific abilities and potential (Milne & Otieno 2007).

To promote scientific literacy teachers must help all students see the value in participating in science, its relevance to their world, and the positive experience it can bring. Students must also feel confident in their reasoning and in their understanding of the nature and process of science in order to apply it consistently, making connections to science beyond the classroom (Fives et al 2014). In addition, to build a student's subject confidence, which influences one's likelihood of pursuing a scientific career (Krogh & Moeller 2013), teachers must be mindful of how they respond to student questions and ideas when teaching about the process of science.

Responses to student questions, predictions, and hypotheses should be carefully tailored to encourage critical thinking and making observations, to promote dialogue, and to build students' confidence in their own scientific reasoning (Katchevich, Hofstein & Mamlock-Naaman 2011, Milne & Otieno 2007). A teacher with an authoritarian presence often creates an environment that intimidates students from asking questions, stifling dialogue, student problem solving, and creativity (Kang & Wallace 2005). According to Fives et al. (2014), "[i]t is not enough for students to be able to know about science or how to engage in science, but that they must actually do so and feel confident about that capability."

Conducting multiple demonstrations illustrating the same concept can be a way of building student confidence. It takes time for some students to feel comfortable participating in discussion and generation of questions, hypotheses, and predictions. However, this must be balanced with the risk of repetition and boredom in order to create an environment that is approachable, but does not seem repetitive. Withdrawn students or those lacking confidence may come to feel safe asking questions, proposing hypotheses, or suggesting questions for further study with subsequent demonstrations and positive classroom energy and feedback (Milne & Otieno 2007).

Emphasis and importance should be placed on building student subject confidence in science classes through positive student-teacher interactions. Students are more likely to pursue additional science education when they identify more closely with their science teachers (if students like their teacher or see themselves as similar) or if their science teacher challenges negative perceptions of the "categorical prototype" of what type of people are scientists (Kessels & Taconis 2012). "Students belonging to marginalized groups do not find science engaging because it often seems irrelevant to their lives and remains inaccessible because its very structures embody ways of being that are associated with being White, middle class, and male" (Milne & Otieno 2007). Students would be more inclined to engaged in the process and pursue scientific literacy for themselves if they were able to see science as approachable, that at its core, science is primarily about asking questions and seeking answers to these scientific questions through hypothesis testing.

Although the curriculum of conceptual chemistry at Grand Ledge High School is tailored for those students who are not bound for science degree programs at the college-level, students should be encouraged to approach their chosen path, science related or not, with curiosity and critical thinking. In past school years, the researcher has observed students who placed themselves in conceptual chemistry due to their low level of confidence in their science skills, yet left the class with an affinity for chemistry and the desire to learn more. The post-assessment to evaluate this project contains response items designed to reveal if this subjective observation can be supported by evidence and if learning the process of science increased student subject confidence.

The Use of Demonstrations in Science Classrooms

Demonstrations are used at all levels, primary, secondary, and post-secondary, and in nearly every subject area of science to engage students and illustrate scientific principles. A body of research supports the use of demonstrations in the classroom to accomplish the aforementioned pedagogical goals (e.g. Beasley 1982, Liem 1992, Milne & Otieno 2007). Other studies warn that demonstrations are not as effective at increasing student understanding of science content or scientific principles as teachers may believe (Roth, McRobbie, Lucas &

Bautonne 1997, Kang & Wallace 2005). This study (the subject of this thesis) endeavored to contribute to this body of research to show that demonstrations can be used to incite curiosity, engagement, and a sense of wonder, and to build excitement about chemistry at the secondary level as well as serve as a vehicle through which to teach the process of science and increase scientific literacy.

A study conducted by Beasley (1982) confirmed the usefulness of demonstrations in generating attention, motivation, enjoyment, and task involvement for science students at the secondary level. Liem (1992) described demonstrations as the use of discrepant events to arouse curiosity and interest in topics. Appealing to natural curiosity and engaging students is especially important for the pupil demographic in conceptual chemistry courses, where students may consider themselves "science outsiders," not bound for a science-centered or science-related professions.

Demonstrations and lab activities are often designed and implemented to challenge students' prior knowledge or misconceptions (Kang & Wallace 2005). For a demonstration to be effective, it must contain an element of the unexpected, even if it is not spectacular. Observing the unexpected creates a dissonance that students are driven to resolve. Therefore, they will be motivated to pursue an explanation of the science behind their observations (Liem 1992). However, teachers must be warned against the misuse of demonstrations. A demonstration must also be accompanied by context. Chemistry has the tendency to lend itself to a misperception of being supernatural, simply because the science is not understood and with mechanisms at the unseen atomic/molecular level. Mysterious and confusing or flashy and circus-like demonstrations do not accomplish the same end goal of understanding resulting from curiosity and wonder as demonstrations conducted with a purpose using guided inquiry cognition (Hadzigeorgiou 2012, Milne & Otieno 2007).

Curiosity and wonder are common ground on which all students can begin the process of learning. A study by Hadzigeorgiou (2012) found that wonder allows those who may see themselves as "science outsiders" to engage in the processing of scientific concepts and to continue to retain ideas and concepts longer. In Hadzigeorgiou's study, students in a traditional class, where the teacher made no targeted effort to foster wonder, retained less information and were less likely to elaborate on the information or to think about it over a period of time. In the class where student wonder was incorporated into teaching, more students became engaged and involved. The use of wonder eliminated a gap found in the control group between the participation of high-academically achieving males and under-achieving males and females of all academic ranges. Wonder helped students focus on the new idea of study and allowed them to pay better attention to it, allowing the researcher to conclude that wonder is a "prerequisite for significant learning" (Hadzigeorgiou 2012). Although Hadzigeorgiou distinguished between wonder and curiosity in his paper, he recognizes the interchangeable use of these terms. For the purpose of this study, wonder and curiosity were considered to be equivalent entities.

Hadzigeorgiou (ibid) found that, "[a] student's experience of a sense of wonder becomes a source for questions". Any teacher of elementary grades could confirm that young students love to ask questions. However, students at the secondary level can be more hesitant to do so (Roth et al. 1997). Could it be that students stop wondering because they believe they already understand? Do secondary students feel embarrassed about asking questions, as though they are less intelligent for asking them?  Or do they truly stop feeling curious, no longer wondering about the world around them?  Regardless of the reason, teachers must make question generation by students a goal in science class as it is one of the most important learning tools a student can access, according to Postman in Hadzigeorgiou (2012).  When asked a question about a demonstration, it is critical for a teacher to assess and probe why the student may have the question he or she asked.  This will reveal misconceptions and errors in logic that a teacher can then address and seek to correct (Roth et al. 1997).

In addition to questioning, engagement is also a requirement for learning.  According to a study by Milne and Otieno (2007) there are three different kinds of engagement:  behavioral, emotional and cognitive.  Behavioral engagement relates to participation in classroom activities and actions and involves persistence, concentration, asking questions, and contributing to class discussions.  Emotional engagement influences a student's willingness to participate due to the combined reaction to peers, teacher, content, and school.  A positive teacher response to a student's participation will increase the likelihood that that student will open him or herself up to participate again.  Cognitive engagement indicates a willingness on the part of the student to exert the effort required to understand difficult concepts.  All of these subsets of engagement must be considered for a learning task to be successful and, since chemistry is seen as a difficult subject, it is all the more critical to engage students on all three levels to increase their successful understanding of the material.  Milne and Otieno (ibid) found that student engagement in all three areas required positive emotional energy to be generated by the activity, in this case, a demonstration.  Teachers can look for evidence of engagement exhibited through student body language, including tracking the demonstration with posture and eye contact, participation in resulting discussion and dialogue, or suggesting hypotheses, predictions, or questions for further study. The more evidence of engagement exhibited by the student, the more successful the learning task will be.

Not only should demonstrations be used to engage and inspire curiosity, they must also target learning of scientific principles. In order to understand the science of the demonstration and not simply be awed by a discrepant event, students must have prior knowledge or be provided context to allow them to put their observations in context and generate the kinds of hypotheses and predictions useful in scientific thinking. Milne and Otieno (ibid) explained that, "successful demonstrations depend very much on the extant knowledge of the observer. Very often students do not have the prior experience, or a demonstration is so far removed from their prior experiences, that students do not 'see' what the demonstration is supposed to show." Roth et al.'s (1997) findings also confirm this conclusion.

One way to activate student prior knowledge during a demonstration is to use everyday items or equipment. This serves the dual purposes of promoting understanding of the demonstration and increasing behavioral engagement. Seeing familiar items behaving in unexpected ways increase the urgency to resolve the discrepancy and lead to greater cognitive engagement (Milne & Otieno 2007).

Roth et al. (1997) criticized the use of demonstrations in a single case-study classroom, but did so mainly due to the nature of the presentation method and lack of context surrounding the demonstration, such that students missed the principles intended for illustration. The recommendations of their study to make demonstrations more effective were to provide students with enough background information to actually focus on the relevant aspects of the demonstration; to acknowledge relevant prior knowledge that can create misconceptions when observing the demonstration; and to allow students time to discuss their observations so they can make the desired connections between their observations and the ideas of the lesson. By adding structure to demonstrations, students could learn from rather than just be entertained by them.

Since a demonstration is a class-wide shared experience, observing demonstrations levels a gap in prior knowledge for some students, allowing them access to participation they may have otherwise denied themselves. Laboratory activities are assumed to be shared experiences as well. However, the observations students make during individual or small group experiments may lead to different interpretations of observations for students in different groups. On the other hand, demonstration experience allows students to process together their shared observations, resulting in a more cohesive understanding of them. Students and teachers can both refer back to the demonstration throughout the unit or in future units and the shared prior knowledge of that experience will contribute to understanding of scientific concepts in the current lesson (Milne & Otieno 2007).

Students often leave science classrooms with misconceptions about the nature of science because most of lab activities they perform were designed to confirm some scientific principle they were learning rather than cause them to explore questions within the subject matter. Even when they perform laboratory activities, students are not truly acting and thinking like scientists (Kang & Wallace 2005, Kessels & Taconis 2012). Coupling demonstrations with the process of science, as in the study of this thesis, was intended to help students think as scientists do. Teachers must think about the goal of the activity, in this case, demonstrations, when planning. Sometimes the goal of the laboratory experience is to confirm what has been taught in order to reinforce understanding of a concept; other times the goal is to work in an open-ended environment to engage students in the process of science through reasoning and hypothesis testing. The intention of this study is to provide a framework to accompany demonstrations to accomplish the latter goal.

When lab activities were designed to confirm a scientific concept, instead of seeking an answer to a scientific question, these experiments did not elicit dialogue (Katchevich et al. 2011) and did not allow students to do the work of actual scientists. Instead students were asked to replicate expected results to acquire a correct answer (Vazquez-Alonso et al. 2012). This communicates a misperception that scientists think and operate in a similar manner and does not reflect the truly tentative nature of science. One might argue that demonstrations are confirmatory, even more so than lab activities because the student is further removed from performing the activity. However, demonstrations can provide an opportunity for students to participate in the process of science, giving it value. If students can be engaged in the practice of using scientific inquiry, or intelligent curiosity (Kirch & Siry 2012), to ask questions, suggest hypotheses, and make predictions, they will have a better understanding of the nature of science and feel more connected to the information they discover.

Students have a limited understanding of the nature of science because the majority of science content is presented as absolute truth by textbooks as well as teachers (AAAS 1989). This authoritarian view of the nature of science causes students to see conclusions as facts in their final form (Duschl 1988). According to Talanquer (2013), "the central problem with school chemistry is that we keep insisting on teaching 'what we know and can explain with that knowledge'." Teachers who use demonstrations without considering the deeper interpretations that can be made from observations are communicating the impression to students that science is a body of facts, rather than a process of problem solving where more than one interpretation of an observation could be correct (Kang & Wallace 2005).

Demonstrations, when structured with appropriate amounts of background information can be a mechanism to engage students, inspire curiosity and wonder, build confidence, and teach the process of scientific thinking and reasoning. Any lab activity or demonstration implemented in a science class should be done so with the intention of helping students think like and behave as scientists do: asking questions, suggesting hypotheses, and making predictions. By doing so, students will have a better understanding of the nature of science, increased science literacy, and will feel more connected to the information they discover.

Application of the Process of Science using Demonstrations

This study sought to determine the effectiveness of demonstrations when coupled with Fred Dyer's (2014) methodology to teach scientific thinking to increase students' subject confidence, scientific curiosity, and knowledge of the process and nature of science for students in a conceptual chemistry classroom. Dyer used videos as demonstrations of animal behavior to arouse curiosity and elicit questions and hypotheses. Applying the same method of scientific reasoning in a chemistry classroom, demonstrations of discrepant events should accomplish the same goal. According to Milne and Otieno (2007) "Science demonstrations have the potential to provide a beginning point for experiencing science, talking about experiences, proposing questions, suggesting patterns, and testing those questions and patterns." In order to teach students about the process of science the use of demonstrations must be “infused with science practice and strategies that interrogate students’ experiences of the world.” With this structured approach to student involvement with demonstrations, “students [will] begin to learn their way around science” (ibid).

To reinforce the relevance of scientific reasoning from one context to another and promote student transfer of skills from science class to broader applications, demonstrations were conducted to begin each of six successive units. In keeping with the philosophy of Patchen & Smithenry (2013), a new demonstration for each unit provided a new context to apply the same process of science procedure, providing repeated exposure and processing time for the practice of scientific thinking to become assimilated (Lawson 1993). Teachers must begin by promoting near transfer of skills by designing new and old contexts with enough similarity to allow students to automatically make connections and apply previously taught methods to new learning. However, in order to promote far transfer, which is the ultimate goal for scientific thinking and literacy, teachers must also frame the learning in terms of social relevance and how the process of science can be applied to the greater context of community participation (Patchen & Smithenry 2013).

Traditionally teachers have used demonstrations to "convince their students of truth," (Kang & Wallace 2005) but instead, the demonstrations in this study, coupled with the process of scientific methodology, were intended to inspire curiosity and questioning that lead to higher scientific reasoning. Milne and Otieno (2007) found “As a result of engagement [through science demonstrations], students participated in a greater range of activities such as writing, asking questions, devising new experiments, and problem solving.”

The Next Generation Science Standards (NGSS) included standards to focus curriculum and instruction on the process of science in addition to the knowledge of science. Standards which apply specifically to this study are: formulate, refine, and evaluate empirically testable questions; evaluate questions that challenge the premise of an argument or the interpretation of a data set; apply scientific principles and evidence to provide an explanation of phenomena, taking into account possible unanticipated effects; construct and revise an explanation based on valid and reliable evidence; recognize that empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects; and communicate technical information or ideas (NGSS Lead States 2013, Appendix 2A). In public school education where teachers are required to justify instruction by correlation with standards, the NGSS provides a platform to substantiate the importance of time allotment for teaching scientific reasoning as well as science content.

## DEMOGRAPHICS

This research was conducted at Grand Ledge High School in Grand Ledge, Michigan. Grand Ledge High School (GLHS) has an annual enrollment of 1,712. Grand Ledge Public Schools reported a graduation rate of 89% in 2012 and a drop out rate of 10.5%. The district wide pupil to teacher ratio is 24:1, which is similar to the ratio found in conceptual chemistry classrooms. Grand Ledge Public Schools services a student population that is 83.7% white, 5.4% Hispanic, 3% Asian, and 5.4% African American. 26% of students are considered economically disadvantaged and in 2012, 100% of eligible students participated in the free and reduced lunch program. In the Grand Ledge Public School System 12.6% of students are identified as students with disabilities, either learning disabilities, emotional, cognitive, or other imparements (MI School Data 2015).

Grand Ledge Public Schools serves both the city of Grand Ledge residents as well as the outlying areas of Oneida and Delta Townships. The city of Grand Ledge has a population of 7,780 people; Delta Township and Oneida Township has a population of 29,682 people and 3,703 people respectively. Households in Grand Ledge, Delta Township, and Oneida Township have a median household income of $50,852, $54,389, and $67,500 respectively. Of the adults who live in Grand Ledge, 30% have completed high school or dropped out of high school, 43% completed some college, and 27% completed a Bachelor’s degree or higher graduate degree. In Delta Township, 27.9% of adults have completed high school or dropped out, 38.6% completed some college, and 33.6% completed a bachelor’s, master’s or doctoral degree. Oneida township had the same percentage of adults complete or drop out of high school as those which completed some college, 27.8% and 44.4% of adults completed a bachelor’s degree or beyond (Delta charter township, Eaton County, Michigan 2015, Grand Ledge, Michigan 2015, Oneida charter township, Eaton County, Michigan 2015).

Students in the conceptual chemistry course of this study were sophomores, juniors, or seniors who successfully completed biology (with few exceptions). There were two levels of chemistry classes offered to students at Grand Ledge High School: conceptual chemistry and a college preparatory chemistry curriculum, simply called chemistry. Students were allowed to choose to register for either of the two courses and both count toward the science graduation requirement of either chemistry or physics as required by the state of Michigan. Students based their choice of course based on anticipated career path and level of completed mathematics, in combination with an interest in the topic.

In order to participate in the study, students had to complete a consent/assent form (Appendix 1A) with their signature and the signature of their parents/guardians granting their permission for their student's data to be used in the data set. Signed consent forms were deposited in a sealed receptacle and were opened by the researcher after the final grades of Trimester 1 had been officially filed.

IMPLEMENTATION

This project studied the participation of students in the process of science in the context of viewing a demonstration at the start of each unit in a conceptual chemistry class. Students were presented with a demonstration, a discrepant event, designed to challenge their senses, insight curiosity, and invoke questions about the unit topic (Appendix 2C). After observing the demonstration, students were asked to spend three minutes generating as many questions as possible. Students were instructed not to make judgments about any questions and to press through a lull in questions until more occurred to them (Appendix 2B). As a class, the students collectively listed their questions, sorting them by idea and type, identifying the testable questions, and choosing one in which to test in class. The answers to the testable question, hypotheses, were collaboratively shared and one was chosen about which to make predictions. The predictions were of what the class would observe if the observation gave evidence to support the hypothesis or to refute it. Hypotheses were then tested to answer the scientific, testable question.

Assessment of student growth throughout the project came from a pretest/posttest comparison (Appendix 4A) as well as comparison of response to questions for each demonstration (Appendix 3A). Students were administered a pretest after a two and a half day series of activities designed to build classroom culture. Students were notified that the pretest was part of the research project. The post-test was implemented on the final exam day, the last day of trimester, after the content exam was administered. Students were aware that post-test was for research and not a grade in the class.

Pretest and posttest assessments were graded with a rubric (Appendix 4B). Scores were tabulated as totals as well as according to topic of question. The first three questions were designed to test a student's knowledge of the nature of science by requiring them to define a hypothesis, explain the process by which a hypothesis could be considered a scientific theory or law, and answer a multiple choice question which asked them to differentiate between science as a body of knowledge and facts and a diverse way of problem solving or scientists' tentative explanations for observations validated through rigorous inquiry processes. Students could score a maximum of seven points on these three questions, two points for the first two questions each and up to three on the third question. Questions five, eight, and ten on the assessment tool determined a student's curiosity score by comparing how many questions they generated on the pretest to how many questions they generated on the posttest in response to a graphic, an article, and a graph comparison. Generating three or more questions for each item earned the student three points, two, one, and zero questions were worth two, one and zero points respectively. The assessment portion with the greatest correlation to the activities performed in the study assessed the students' ability to apply the process of science methodology to a prompt closely resembling the Unit 5 demonstration. Students were asked to record as many questions as they could in response to the description of an observation of a discrepant event, choose the most testable question, and record two hypotheses. Then they were asked to choose one hypothesis and make predictions of what evidence they might observe which would support or refute it. Students could earn up to three points each for the hypothesis and question generating items and up to two points for each of the prediction items, one to support and one to refute the hypothesis, for a total of 10 points on the process of science section.  Lastly, the assessment tool asked students to self-report on their confidence in their science abilities by asking them to rate five statements on a scale from one to five, where one was strongly disagree, two disagree, three neutral, four agree, and five strongly agree.  The statements to evaluate confidence were:  1) I am good at science, 2) I am good at chemistry, 3) I would voluntarily take another high school science class, 4) I would voluntarily take a college-level science class, and 5) I am likely to go into a science-related profession. Ratings for these five statements were totaled and given a point value of two, one, or zero in the rubric scoring.  A total rating of on these five items of 25-17 was worth two points, 16-9 was worth one point, and 8-5 was worth zero points.  Also scores reported for the first two items totaled separately from the last three, where a score of 10-7 was worth two points, 6-4 was worth one point, and 3-2 was worth zero points.  The last three items totaled separately  had a point value range of 15-10 worth two points, 9-5 worth one point, and 4-3 worth zero points. The rubric points were then totaled for each student with a maximum score of six and a minimum score of zero for a confidence score.

Total score on pretest and posttest were evaluated with a paired t-test as well as scores for the areas of curiosity, confidence, knowledge of the process of science, and the nature of science each with a separate paired t-test.

ANALYSIS OF ACTIVITIES

The first unit of the course was a study of acids and bases. The demonstration for this unit was called the "Magic Pitcher" (Appendix 2C) and used a solution containing the indicator phenolphthalein and a series of acids or bases hidden in the bottom of cups to change the color of the liquid as it was poured into the cups. Students were led to believe that the fuchsia-colored substance was raspberry kool-aid and that the clear substance was drinking water. Before being asked to participate in the process of science, students were instructed that the all-encompassing scientific question was "What's up with that?" as stated by Dr. Fred Dyer, but that the job of scientists was to expound upon that question in order to shed light upon what seems mysterious to an observer. Students were encouraged to be as curious as possible and were told that one of the most important traits of a scientist was a burning curiosity to understand the world around them. Students were encouraged to celebrate any time they asked the same question as one of their peers, acknowledging that humans are all curious about similar things and also to celebrate the length of the list of questions the class generated, since that indicated that humans are curious about many, many things (Dyer 2014, Appendix 2B). Students actively participated in question generation and testing hypotheses. The testable question each class chose to explore was "What could be in the cup that caused the color to change?" Hypotheses varied greatly and included testable substances: lemon juice, vinegar, bleach, ammonia, salt, hydrogen peroxide, and acids and bases in general, as well as other untestable substances: clear paste, special plastic, a certain kind of chemical, a dissolved solid. Students chose one of the chemicals on which to base predictions. Three of the four classes chose the hypothesis that lemon juice was the chemical that turned the liquid fuchsia. A prediction of observations that supported this hypothesis was that clear liquid turned fuchsia in the presence of lemon juice in a cup. Predictions of observations that would offer evidence to refute this hypothesis were if nothing happened, clear liquid stayed clear, or a different color was produced. The instructor gathered as many of the suggested substances as possible, added them to the bottom of cups, and poured liquid from the pitcher over each while students observed and assessed.

The Unit 1 demonstration was one of the most successful of the activities for a number of reasons. One reason was that there was enough time budgeted for it. The issue of time became a limiting constraint as the trimester progressed. The conceptual chemistry curriculum was written to deliver the content through 71-minute lessons over 53 or fewer school days. There was very little room for adjustment of this timeline to accommodate the amount of time that the process of science required. Curiosity, creative thinking, and problems solving are processes that require time to be fully experienced. The demonstrations and process of science analysis could potentially have been given 50 minutes, but required at least 30 minutes. In past years, the demonstration activity was allotted 10 minutes maximum and sometimes none at all. Another reason the Unit 1 demonstration was successful at generating curiosity and questions was the high level of prior knowledge the students possessed and applied to their questioning. Students generated an average of 12 questions per class, 11 of those were considered testable. The chosen testable question to investigate, “what could be in the cups to produce the observed result?” was easy to answer by suggesting familiar substances from their everyday lives. This was a trend that prevailed throughout the study – the more prior knowledge students possessed, the greater the depth of questions they were able to generate.

The second unit of study was the properties of matter, including distinguishing between physical and chemical changes. Students were asked to learn five pieces of evidence which can be observed to indicate a chemical reaction has taken place: production of light, generation of gas, change in heat energy, color change, and precipitate formation. The demonstration at the beginning of this unit was called the Iodine Clock-Reaction, a dramatic chemical change with a delayed color change and precipitate formation. The delay of the reaction was the part of the demonstration that students wondered about the most, causing them to ask, "what would happen if you used different amounts of each reactant liquid?" Hypotheses included: the speed of reaction would increase or decrease, the color change would be more or less, no change in result, different color, explosions. In fact, explosions (a combustion reaction producing heat, light, and sound) were suggested as a possible hypothesis for almost every demonstration. This hypothesis was never criticized, only acknowledged that some hypotheses are more likely than others based on the scientist's knowledge of the chemical nature of the substances involved. To test the hypothesis the instructor had prepared a series of solutions with varying amounts of potassium iodate ($KIO_3$) and combined it with a constant solution of potato starch and sodium metabisulfite. Students took time measurements to compare the concentrations of $KIO_3$ and its effect on the rate of the reaction. Students timed the rate of color change and precipitate formation and found that as the amount of $KIO_3$ increased, the time for the reaction to occur decreased.

In the Unit 2 demonstration, students used their experience with the process of science from the first unit to make hypotheses and predictions more quickly than the first unit. However, their lower level of prior knowledge related to this demonstration caused them to ask fewer testable questions, two fewer on average per class than the Unit 1 demonstration. Despite their growing familiarity with the process of science they were only able to ask an average of 0.5 more questions than the first unit, suggesting the negative impact of a lack of prior knowledge on the ability to articulate curiosity and pose testable questions.

The third unit of study in conceptual chemistry was gas laws. Objectives for this unit required students to identify how volume, temperature, and pressure influence each other within gases. Students were taught Boyle's Law, Charles' Law, and the Combined Gas Law. Since conceptual chemistry focuses on reducing the mathematics in chemistry students were not required to memorize formulas or to demonstrate an ability to reformulate formulas to solve for each variable. Students were, however, required to explain how the behavior of gases under certain conditions of pressure and temperature caused the results of many different demonstrations and experiments. The demonstration at the beginning of the unit, before instruction was given, was a can crushing demonstration where a can was heated with a small amount of water in the bottom and, once steam escaped, was inverted into a shallow bowl of water and became crushed by the air pressure outside the can. Each class chose a slightly different testable question to investigate. Three of the four classes chose to ask if the size of the can would influence how fast the air pressure could crush the can. In one of those three classes, students also wondered if the brand of the pop can would have a difference on the rate of crushing. These questions were tested when students brought in different cans from their home or lunches and crushed them using the same method as the initial demonstration to find that the speed was the same regardless of the size of can or the brand of pop. One class asked if the can would crush in the same way if water had not been placed in the bottom of the can while heated, but some other liquid. Some pop was left in one can and water was placed in the other. It was found that the same speed of reaction occurred but that the can with the pop in it was considerably less pleasant to heat due to the burning of sugars within the pop liquid.

For the Unit 3 demonstration, students generated an average of 17.25 questions per class. Of the six unit demonstrations, students were able to generate an average of five more questions for Unit 3 than the demonstrations than those with the lowest number of questions generated and three questions more than the demonstration with the next closest question total. High prior knowledge allowed students to respond quickly when asked to make hypotheses and predict the observed results that would support or refute a chosen hypothesis. This demonstration was negatively influenced by time constraints. The classes were not able to finish the process of science analysis on the same day as the initial demonstration, therefore it was completed later in the unit as time was found. Some classes had to wait until the very end of the unit to complete their hypothesis testing.

The fourth unit in conceptual chemistry was a unit exploring models of atomic structure and focused specifically on the structure of the nucleus, including radioactive nuclei and different kinds of decay. The intangible nature of subatomic particles made a demonstration more challenging. A cloud chamber was used to generate alpha and beta particles from the radioactive decay of thorium and radium within a lantern mantel. This was the least successful demonstration because it was hard for students to see and in some classes, very few particles were emitted at all. These issues were caused primarily because the radioactive source had been allowed to soak in the isopropyl alcohol used for cloud generation. This caused the particles not to freely move about in the chamber as they do when the particle-emitting sample was dry.  This demonstration was influenced more than any other by a lack of time.  Two classes were asked to view a video of the demonstration at home rather than see it in person. For all classes, time constrains caused the discussion of the process of science to be eliminated and students were asked to complete the questioning, hypothesis, and prediction portions of the process on their own without class-wide collaboration or teacher facilitation.  Therefore, analysis of participation in this activity gave the most insight into student's ability to navigate the process of science independently.  Students who saw the cloud chamber in person tended to ask about the dry ice used to generate the cloud and if ice made from water would have the same effect.  Participation in the process of science hypothesis and prediction portions flowed well from these kinds of questions and therefore, students who chose this question to "test" completed the process well.  Those who had to view the demonstration via a video did not generate a testable question as easily and were more likely to generate a question regarding the apparatus itself:  "is it cold or hot in the chamber?" or "will the glass shatter?"  Students who did ask these questions did their best to complete the hypothesis and prediction components in the same way as modeled in the previous demonstrations done as a class.

The fifth unit of study in conceptual chemistry was a unit on the production of light by electrons, the electromagnetic spectrum, and electron configurations at ground state.  To illustrate electrons producing light, a glow stick was used.  To produce a discrepant event, after mixing the chemicals from a glow stick, the liquid was divided evenly and placed in two test tubes, which were submerged in either an ice bath or a hot water bath.  This demonstration elicited many questions regarding the relationship between students' prior knowledge and the results they observed.  Half of all questions generated were testable and students took a greater role in choosing which should be tested and the predictions of what would happen than in previous demonstrations, testing their ability to work through the process of science without teacher intervention. Two of the four classes chose to ask what would happen if the test tube in the hot water bath were placed in the ice water bath and vise versa. They found that the intensity of light production decreased in the hot-to-cold test tube and increased in the cold-to-hot test tube. One class asked if light intensity would be greater if a test tube were placed in a bath of boiling water compared to the hot water bath. They found that only a slight increase could be observed, but that there was a greater amount of light produced by the glow stick chemicals in the boiling water bath. Finally, one group asked what would happen if glow sticks of different colors were mixed together. Although this question did not directly relate to the hot and cold portion of the discrepant event, the question was testable and so they were able to make hypotheses and predictions regarding the result of mixing. They found that when orange and blue glow stick chemicals were mixed, both orange and blue were present, no new color was produced and the colors did not blend together. Students found this demonstration to be highly enjoyable due to the level of control they had over the testable question chosen and were therefore quite interested in the results of the testing.

The sixth unit of study in conceptual chemistry was a study of the different periodic trends found on the periodic table. Reactivity, atomic size, ionization energy, and type of substance were the trends students were asked to learn. Alkali metal activity and reactivity with water was chosen as the trend to illustrate through demonstration. Although some of the lighter alkali metals were safe to react in front of students, the heavier ones become more dangerous so videos were used to show the reactivities of lithium, sodium, and cesium with water.  The instructor chose to show videos for all three reactions because, although sodium was available in the school's chemical stock, lithium had not been ordered in time and alkali metals heavier than sodium would not have been safe to demonstrate with under school conditions.  Students watched videos produced by the Periodic Table of Videos group from the UK.   Students generated the second highest number questions on average, 14.25 questions per class, for this demonstration series.  This was due to the fact that there were three reaction videos to observe and students took time to generate questions between each reaction.  Using videos instead of a live demonstration did not seem to inhibit the students' ability to navigate through the process of science.  However, viewing the reactions on video, not in person, may have influenced how impressed they were by the reactions. Predictions and hypotheses were generated but not tested due to safety.  This illustrated that the process of science could be applied even outside of the classroom, using scientific thinking to study any problem or question.  Two of the four classes asked about the temperature of the water, hypothesizing that warmer water would generate a more violent reaction from each of the metals.  The other two classes asked if chemicals other than water would produce a similar reaction when alkali metals were placed in the same reaction container

In general, the greatest factor influencing the implementation of this project was time. Adding the process of science analysis to demonstrations, the time required to complete the demonstration and analysis was three to four times the previous amount, or placed an activity where none previously had been.  The trimester timeline is not a very forgiving one and the end of the trimester deadline influenced the amount of time that could be spent on these activities. In a 55-minute period, semester timeline, compared to a 71-minutes trimester schedule, many of these process of science activities could have taken approximately an entire period to allow for ample question generation and allow students more time to think through predictions and hypothesis generation.

When completing the demonstration and process of science analysis, most students were very active in the process and generated many thoughtful and scientific questions.  Still one of the more frequently asked questions was, "how did you do that?" or "why this or that?" rather than questions that could be tested and answered.  By the sixth unit, students were more able to identify testable questions as those which do not begin with why and to rephrase why questions into testable questions.

The pretest and posttest assessment (Appendix 4A) process was also influenced by the time constraints.  Both the pretest and posttest relied on intrinsic motivation as the only incentive for student performance.  The posttest was given following the content exam on the last day of the trimester.  Posttest scores of some, if not many, students may have been influenced by fatigue from testing or a desire to complete the posttest quickly in order to study for exams in other courses.  This observation led the researcher to ask, if a correlation between final grade in the course and difference between pretest and posttest scores existed.

RESULTS

Data collected from four different class periods contained two sets of 17 student scores and two sets of 16 student scores totaling 66 sets of data for analysis. The first hour of the day had a pretest class average of 21.5 points out of a possible 41 points and a posttest average of 28.4 points out of the same. The second hour of the day had a pretest average of 21.1 points and a posttest average of 24.1 points. The third class period had a pretest average of 19.4 points and a posttest average of 21.1 points. The fourth class period had a pretest average of 19.0 points and 21.1 points on the posttest. Although each hour showed improvement as a whole, only the first hour group showed a statistically significant amount improvement, according to a paired t-test, from pretest to posttest (p value = 0.008) causing the author to reject the null hypothesis for this class that pretest and posttest scores were statistically the same. The other three hours had p values of 0.289, 0.494, and 0.475 respectively, leading the author to accept the null hypothesis that the pretest and posttest scores were the same. Pretest and posttest averages by hour are shown in Figure 1.

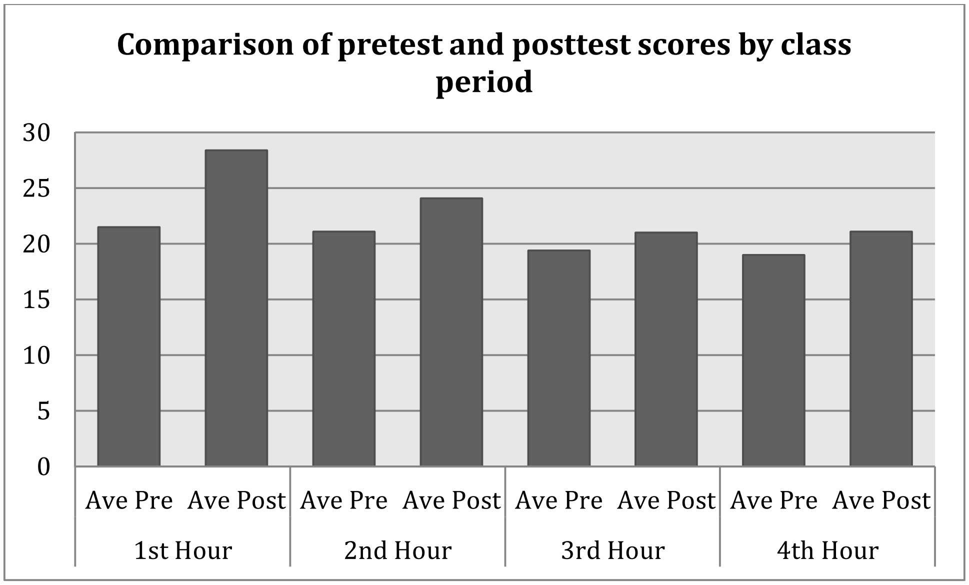


Figure 1. Posttest averages were higher than pretest averages for every hour. These differences were not statistically significant according to paired t-test results for all but the 1st hour class. ($n_{1st}$ = 17, $n_{2nd}$ = 17, $n_{3rd}$ = 16, $n_{4th}$ = 16)

Since class averages did not show statistically significant difference, subgroups earning each of five letter grades as their final grade in the course (A, B, C, D, and F) within all four classes were analyzed to determine if, for example, a group of students earning As in the course for all classes showed a statistically significant amount of improvement on the posttest. In all five letter-grade categories, a greater degree of statistical difference was observed between pretest and posttest averages than when the same scores were sorted according to hour of attendance. Pretest and posttest averages by grade earned in the course are shown in Figure 2.

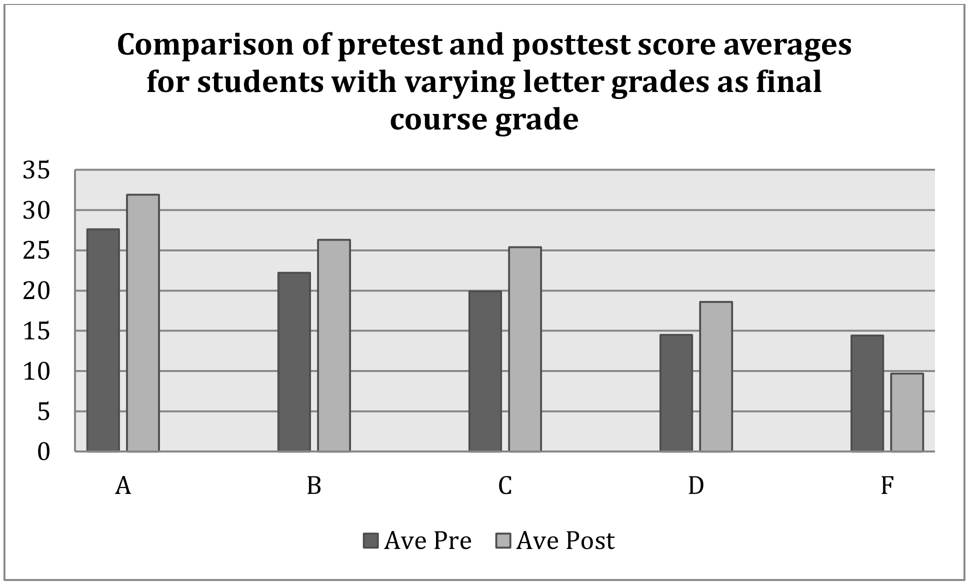


Figure 2. Pretest and posttest averages compared among students within five letter grade categories with paired t-tests showed groups A-D had statistically significant differences. The F group did not show statistically significant differences between pretest and posttest and had a negative direction of change. ($n_A$ = 8, $n_B$ = 21, $n_C$ = 21, $n_D$ = 11, $n_F$ = 5)

Students in the A letter grade category (n=8), those who earned a grade between 90% and 100% in the course, had an average of 27.6 points on the pretest and 31.9 points on the posttest with a statistically significant p value of 0.043. Students in the B letter grade category (n=21), those who earned a grade between 80% and 89% in the course, had an average of 22.2 points on the pretest and 26.3 points on the posttest with a p value of 0.078 which, although not statistically significant, shows a slight tendency toward significance. Students in the C letter grade category (n=21), those who earned a grade between 70% and 79% in the course, had an average of 19.9 points on the pretest and 35.4 points on the posttest with a statistically significant p value of 0.009. Students in the D letter grade category (n=11), those who earned a grade between 60% and 69% in the course, had an average of 14.5 points on the pretest and 18.6 points on the posttest with a p value of 0.072 which although not statistically significant, shows a slight tendency toward significance. Students in the F letter grade category (n=5) did not show improvement from pretest to posttest. Scores for students in this category were lower on average on the posttest than on the pretest. The pretest average was 14.4 points and the posttest average was 9.70 points with a p value of 0.233. Students in the C letter grade category showed the greatest degree of improvement from pretest to posttest score.

The assessment contained questions designed to assess a student's curiosity to determine if practicing the process of science and being encouraged to ask questions would cause them to become more curious or inquisitive when looking at data, figures, or an article about scientific findings. Curiosity was measured by the number of questions a student asked when prompted to do so. On the assessment, asking three or more questions earned three points, two questions two points, one question one point, and zero questions zero points. There were eight possible points for curiosity. Results of curiosity scores compared for each letter grade group can be found in Figure 3. Although four of the five letter grade categories showed slight improvement in their curiosity averages from pretest to posttest, the fifth group did not show improvement in this area, nor any of the other areas. None of those improvements were statistically significant according to a paired t-test.

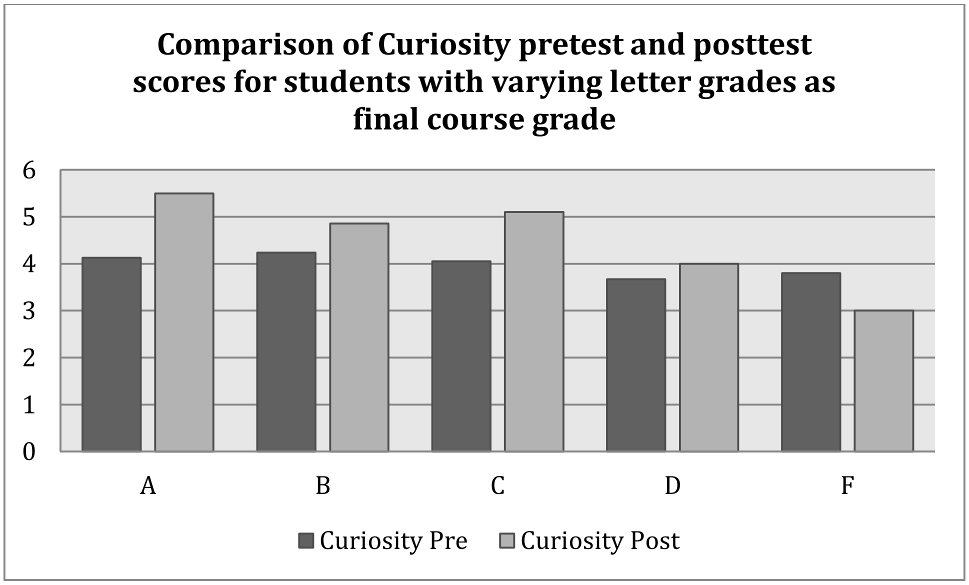

Figure 3. Each group (except for the F letter grade category) showed improvement, small but not statistically significant according to a paired t-test, in their curiosity scores. ($n_A = 8$, $n_B = 21$, $n_C = 21$, $n_D = 11$, $n_F = 5$)

Confidence was measured within the assessment with a series of self-reflection questions in which students were asked to rate their confidence in their abilities in science and chemistry and their likelihood of voluntarily taking additional science courses during high school or post-secondarily (Figure 4). Students in the A letter grade category showed the greatest degree of difference between pretest and posttest scores in this area, from an average of 3.5 points out of 6 points on the pretest, to an average of 5.5 points on the posttest, with a p value of 0.005. Confidence averages improved as well for both the B and C letter grade categories but by less than the A group. In the B letter grade category, the pretest average was 2.19 points and the posttest average was 3.33 points with a p value of 0.056. The C letter grade category increased the pretest average of 3.3 points to 4.4 points on the posttest with a p value of 0.055. In the D and F letter grade categories, averages were too similar to be statistically distinguishable from one another. And as in the case of all tested areas for the F letter grade category, the confidence scores decreased from pretest to posttest.

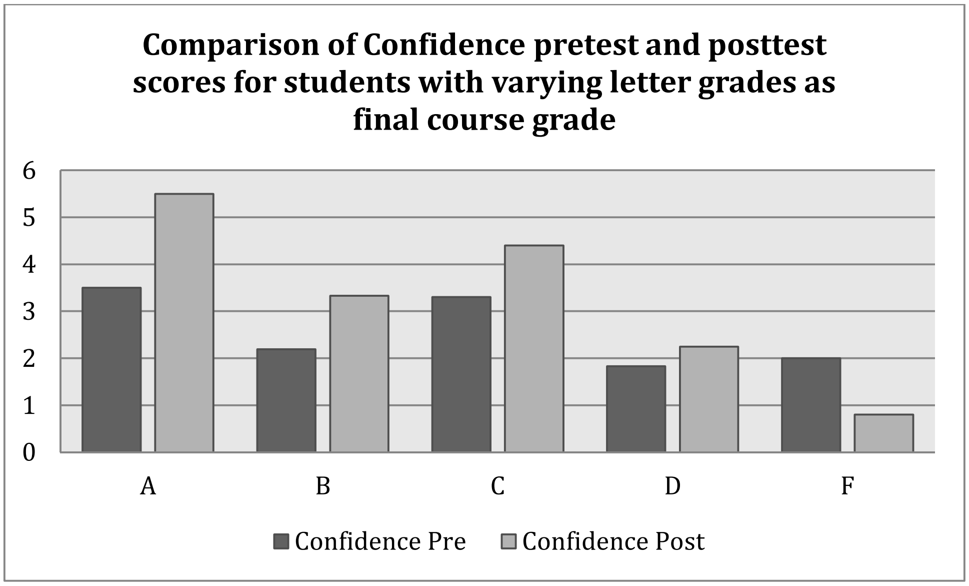


Figure 4. Confidence scores improved for all letter grade categories expect for those students who earned an F in the course. Scores for A, B, and C categories showed statistically significant differences according to a paired t-test. ($n_A$ = 8, $n_B$ = 21, $n_C$ = 21, $n_D$ = 11, $n_F$ = 5)

Knowledge of the process of science was measured through the students ability to generate questions, at least one being testable, proposing hypotheses as the answer to the scientific question, and finally predicting the results that would support or refute a chosen hypothesis. This area of the assessment was the most correlated to the activities performed within the study itself. Students were given a prompt of a description of a demonstration similar to the Unit 5 demonstration of glow stick chemicals in varying temperatures of water, impacting the brightness of light emitted. Results of the process of science scores compared for each letter grade group can be found in Figure 5. Students in the A letter grade category scored so well on the pretest in this area that there was little room for growth to be shown. Out of a possible 10 points, these students scored an average of 8.5 points on the pretest and 9.0 points on the posttest. With 75% of students scoring a 9 or a 10 on the pretest and 83% of students scoring the same on the posttest, the degree of improvement could be nothing but minimal.  Students in the B and C letter grade categories show high degree of improvement between the pretest and posttest scores in this area.  B students earned an average of 5.8 points on the pretest and 8.3 points on the posttest with a p value of 0.006, showing a statistically significant improvement.  Students with a C in the course earned 4.64 points on the pretest and 7.00 points on the posttest with a p value of 0.017.  Two data points were excluded from the statistical calculation of the C letter grade category as the pretest and posttest data for these individuals were incomplete, meaning the individuals responded to the process of science items on their pretest, but neglected to respond to the same items on the posttest.  As it was with the confidence scores, so also is it with the process of science scores for the D and F letter grade categories.  Students with a D in the course did raise their average from pretest to posttest but not with any degree of statistical significance.  Three student data points were omitted from this statistical calculation due to an incomplete data set.  Students in the F letter grade category had a lower average on the posttest than on the pretest.  This was mainly due to that fact that three out of five students chose not to respond to this section of items on the pretest and four out of five students did the same on the posttest.  However, if these data points were excluded due to incomplete data sets, no average could have been taken.

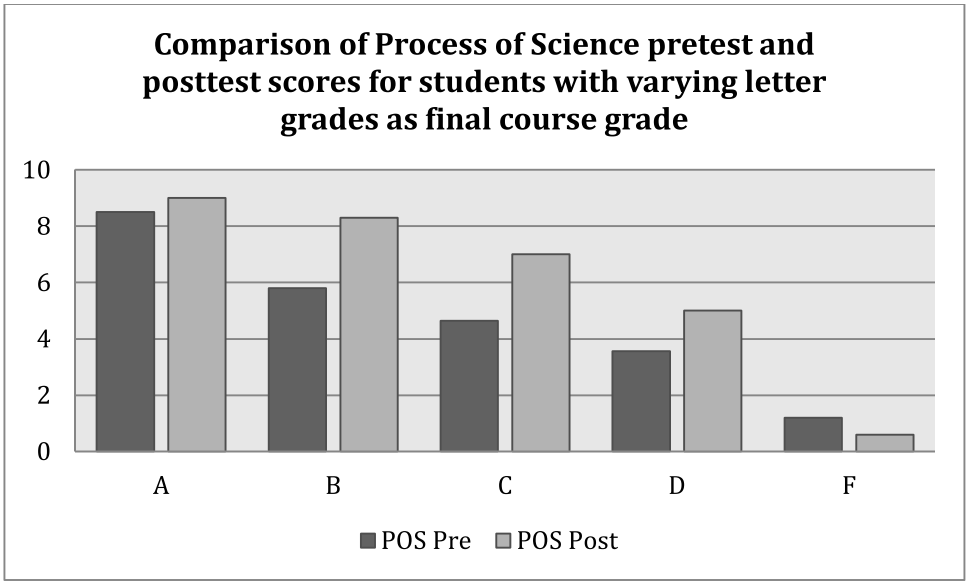

Figure 5. Process of science (POS) scores showed a greater degree of statistically significant difference for B and C letter grade categories than for A using a paired t-test. F letter grade category showed lower scores on the posttest. ($n_A = 8$, $n_B = 21$, $n_C = 19$, $n_D = 8$, $n_F = 5$)

Results of the nature of science section showed no statistical improvement from pretest to posttest for any of the letter grade categories. Scores for this category came from the assessment of students' definition of hypothesis, their explanation of the difference between a hypothesis and a theory, and their response to a multiple choice question regarding whether science is a process, a collection of facts, fixed or changeable, or a combination there of. Students tended to respond in extremely similar ways on the pretest and the posttest, lending evidence to the conclusion that teaching the process of science does not significantly alter a student's understanding of the nature of science. Results of the knowledge of the nature of science scores compared for each letter grade group can be found in Figure 6.

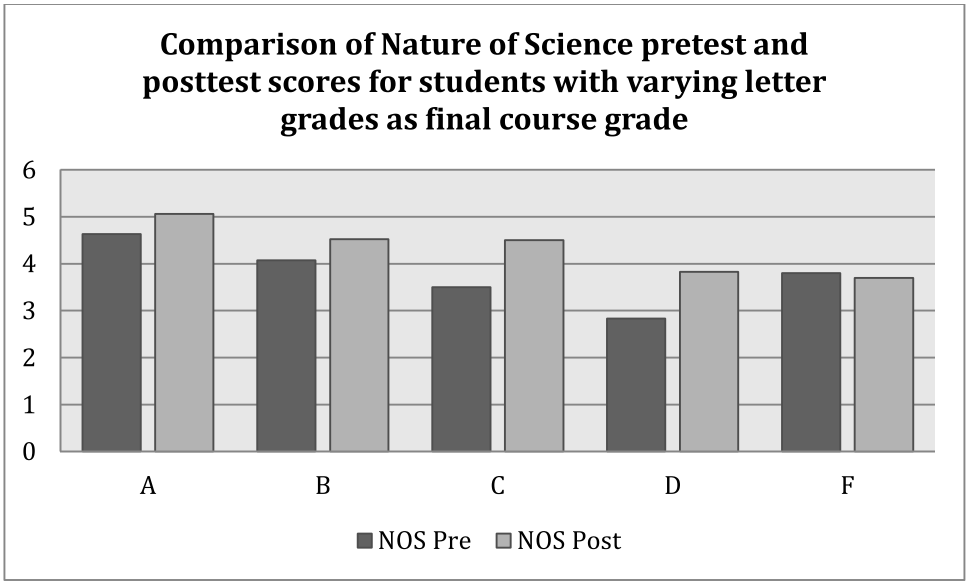

Figure 6. Nature of science (NOS) scores showed very little change from pretest to posttest. None of the changes were statistically significant according to a paired t-test ($n_A = 8$, $n_B = 21$, $n_C = 21$, $n_D = 11$, $n_F = 5$)

DISCUSSION

Comparing class averages of pretest and posttest performance showed no statistical significance for three out of four classes using a paired t-test. One reason is the great degree of range for the high and low performance of students in each class. Although many individuals did show improvements from pretest to posttest, others showed very little improvement, and still others performed more poorly on the posttest than on the pretest. This meant the range of scores and the averages were not greatly different between the two assessments. One factor that contributed to a lower than expected performance on the posttest was that the posttest was given after the final exam on the last day of the trimester. Students probably became increasingly fatigued by the battery of testing over a two-day exam period, putting less of their effort into a post-assessment that had no bearing on their overall grade in the course. It may be for this reason that first hour had a statistically significant result, but the subsequent hours did not.

When grouped according to letter grade, student scores showed statistical significance or a trend toward significance between pretest and posttest performance as shown in Figure 2. The greatest degree of significance was for the A and C letter grade category (p value below 0.05), but B and D letter grade categories were only slightly above the p value of 0.05 and still below the p value 0.08. Comparison according to letter grade controlled for the great degree of range of performance within each class period grouping. Students who performed higher in the course also performed higher on their pretest and posttest on average than other groups, and students who performed lower in the course also performed lower on the pretest and posttests than the higher performing student categories. Improvement from pretest to posttest for each letter grade category (except F) supports the conclusion that using demonstrations coupled with the process of science were an effective way to incite curiosity and wonder and to increase student confidence in their scientific abilities as was found by many other researchers including Beasley (1982), Liem (1992), Reagan (2012), Roth et al. (1997).

This study confirms the necessity for students to possess some degree of prior knowledge in order to interact more effectively with a demonstration as reported by Milne and Otieno (2007) and Roth et al. (1997). Demonstrations that involved chemicals more familiar to students (glow sticks, acids and bases) or familiar items behaving unexpectedly (pop can heated and inverted in water, metals being placed in water and then reacting violently) invoked a larger amount of generated questions than those whose chemical components were more mysterious (the reaction of potassium iodate and a starch solution to produce a dark precipitate, a radioactive source emitting alpha and beta particles in a cloud chamber). If students had difficulty understanding or "seeing" what the demonstration was trying to show they were less able to engage in the process of science to generate questions to which they could find an answer to increase their understanding of their observations.

A lack of statistical significance of the improvement in the area of curiosity may be attributed to a number of factors. One, curiosity was not an overt emphasis in the activities performed in class. Curiosity was encouraged, but students were not instructed on how to take a question such as "how did that happen?" and pose it in different ways as to result in questions for which they could possibly seek an answer. Therefore, this broad question was seen to be all encompassing by many students and they were unwilling or unable to expound further. To help students improve their ability to generate questions, instruction should be given on how to take a general question and expound upon it, drawing a greater number of questions out of it. This same trend was confirmed by Hadzigeorgiou (2012) whose work with wonder and question generation found that direct instruction fully incorporating wonder was necessary to increase student engagement and involvement in the process of science. Although instruction was given to encourage curiosity and wonder throughout this study (Appendix 2B), direct teacher instruction is often not enough to make lasting impact on behavior. Students must come to see how curiosity is useful through their experience (Hadzigeorgiou 2012), not just from the words of an instructor.

Another reason for the lack of statistically significant improvement in curiosity score on the assessment (Appendix 4A), was that students were expected to ask questions regarding a number of topics with a maximum number of points awarded for three or more questions. When a student was able to ask more than three questions on the pretest, the rubric was unable to register growth if a greater number of questions were posed on the posttest. The first curiosity-assessing item was a picture of a fish out of water on a dock. Many students were able to pose three or more relevant questions about this picture on the pretest and therefore could not show improvement in the posttest according to the rubric, which scored a response of three or more questions with the same point value. The second test of curiosity came from an article about the effect of daily, low-dose aspirin on pancreatic cancer patients. The item in the assessment asked students to list two questions for further study, expecting them to find the two questions posed by the article's author within the text. In fact, few students picked up on the article's author's questions for further study, and instead posed their own. However, because of their limited background knowledge of the effect of aspirin on the body, the questions they were able to ask were very limited, the most interesting one being "if low dose aspirin is good, what about a higher dose?" which was posed by quite a few students. The third and final curiosity assessment came from a figure comparing the earnings of men and women since the 1960s correlated to level of education. Within these charts there was a lot to interpret and question. Many students did recognize and ask meaningful questions related to the data set, yet still a large portion of students misread the axis and title of the graph and asked questions that were irrelevant to the data presented. Because the rubric stated "number of relevant questions," questions asked that did not come from the figure's data were not scored. The problem with this scoring was that curiosity and relevant question generation are not one in the same. Students who asked questions, although not relevant to the data set, were still curious about something, yet according to the rubric, had a score of zero regarding curiosity in this area.

Student ratings of confidence in their scientific abilities did show statistical significance for the three higher achieving groups. The greatest degree of significance for differences between pretest and posttest scores came from the A letter grade category. Higher confidence scores suggest students may begin to see themselves as able to access the reasoning and problem-solving methodology from science class when a relevant situation presents itself outside of class. This would make these students "competent outsiders" according to Feinstein (2011). Whereas those whose confidence score decreased, as it is with the lowest performing groups in this study, would see themselves as "marginal insiders," unable to find a situation outside of science class where scientific reasoning might seem relevant and useful because they were not confident in their ability to use this reasoning within the classroom (ibid). Although it is interesting to consider a student's confidence level before and after a course, it is the author's position that the six process of science activities had less to do with inspiring confidence in a student than performance on course material assessments and overall enjoyment of the subject. According to subjective questioning at the end of the trimester, students expressed more confidence in the units and topics most that they found easiest and performed the best on. Students who take conceptual chemistry rarely, if ever, express feeling enjoyment over struggling to understand something, even if they eventually do understand, or at least perform well on the assessment of the unit. Therefore, although confidence and performance in the class seem to be correlated, a causal relationship between confidence in science and the process of science activities cannot be confirmed. This study agrees with Milne and Otieno (2007) that a major challenge in science education is to engage "marginalized groups" of students in the process of science and help them to find it relevant to their lives. Teaching the process of science alongside a demonstration and administering a post-assessment with no tangible incentive, as in this study, was not enough to encourage the lowest performing, most marginalized students to show an improvement from pretest to posttest scores. Higher scores on the pretest for these lower performing students, especially in the area of confidence, may have resulted from a positive connection with their instructor as suggested by Kessels and Taconis (2012), due to the activities performed in the first two days of the trimester to build classroom culture. However, at the end of the trimester, struggling students found it harder to connect with the instructor and see themselves as similar to him or her, and therefore decrease in their confidence to be a scientist (ibid). Positive emotional energy is required for engagement in learning tasks, according to Milne and Otieno (2007), which, for the lower performing student, becomes a downward spiral: as they begin to struggle they feel less positive emotional energy toward chemistry, therefore they engage less in the activities, and struggle more on the assessments.

The pretest performance of A letter grade students in the process of science section shows that students with high aptitude were easily able to pick up the process of science with no formal instruction from the teacher of this course. This may be attributed to high retention of process of science instruction from previous science courses, or simply an ability to question, hypothesize, and predict when asked to respond to any topic, within science or without. With such high pretest scores, improvement in this area was not attainable within the confines of the rubric. Students in the B and C letter grade category showed great improvement with the process of science after instruction and practice, lending evidence to the conclusion that teaching the process of science through demonstrations in a conceptual chemistry classroom will lead students to grow in their ability to ask testable questions, make hypotheses, and predict the results of an experiment to test a hypothesis. As was also found by Lawson (1993), increasing a student's prior knowledge and exposure to the process of science between pretest to posttest assessments was associated with increased a student's performance in question, hypothesis, and prediction generation. After performing the process of science six times, once per unit, B and C students were able to more correctly navigate the process of science on the posttest. The performance of the students in the D and F letter grade categories lends more evidence to a conclusion that proper motivation and incentive must be provided for lower performing students to rise to a challenge than to a conclusion about the usefulness of teaching the process of science in a conceptual chemistry classroom.

The results of the nature of science assessment portion indicate that students of all performance levels have extremely entrenched prior knowledge or none regarding the nature of science. Explicit instruction and targeted activities must be implemented in order to have significant impact on a student's conclusions in this area, regardless of the student's level of ability or performance (Vazquez-Alonso 2012). Simply teaching students how to do science through the process of science method does not seem to significantly change their understanding of the nature of science as a study or body of knowledge, according to these results.

CONCLUSION

Teaching students the process of science methodology as outlined by Fred Dyer (2014) is productive at the high school level in increasing a student's ability to ask questions, generate hypotheses, and make predictions of the result of an experiment to test a hypothesis. This study found that students with high academic performance will pick up the process of science more quickly, but work must be done to engage the lower performing student in the process of science. However, teaching the process of science as done in this study may not promote student curiosity, confidence, or knowledge of the nature of science, but can be correlated to an increase in confidence and a slight influence on curiosity and nature of science knowledge on average. Adding the process of science framework to demonstrations increased student participation in and the number of questions they are compelled to ask about demonstrations. Engaging students in thinking like a scientists required a significant allotment of time in the curriculum to teach the process of science methodology and ample opportunities to apply it over multiple relevant and meaningful experiences tied into the curriculum. Yet, when students were given appropriate context and a discrepant event to ponder, this study found the majority of students were able to generate testable questions and predict the outcome of tests to evaluate answers to their questions.

Due to the time constraints of the trimester schedule, the researcher did not continue to implement the process of science methodology along with the demonstration for each unit in the following trimester. The demonstration remained in place as an activity to begin each unit. However, the student interaction with the demonstration was reduced to simply listing observations, questions, and predictions in a more simplistic way with no in-class opportunities for testing or analyzing. If the researcher were to re-implement the process of science methodology, it would require a rewriting of each unit outline to accommodate the amount of time necessary to complete this activity. Rewriting the curriculum to include the process of science methodology continued to be a recommendation of the researcher because, according to the data of this study, it has shown positive impact on students' ability to analyze a discrepant event using the reasoning of scientists.

Improvement of B and C students on the process of science section of the assessment tool was one of the most important findings of this study. Teaching the process of science methodology to average performing students had a large degree of impact on their ability to interact with observations of a discrepant event using the reasoning and language of scientists Therefore, due to the influence of performing the activities of this study, these groups of students have a greater likelihood of using this reasoning to seek answers to questions scientifically in situations outside of the science classroom (Feinstein 2011).

APPENDICES

# APPENDIX 1

# FORMS

APPENDIX 1
PARENTAL CONSENT AND STUDENT ASSENT FORM

Dear Students and Parents/Guardians:

Along with teaching Conceptual Chemistry, I am currently pursuing a master's degree at Michigan State University. This trimester I will be conducting a research project as part of my degree program and I would like to take this opportunity to invite your child to participate. There are no unique activities related to this research and participation in this study will not increase or decrease the amount of work that students do. Researchers are required to provide a consent form like this to inform you about the study, to explain that participation is voluntary and to explain risks and benefits of participation.

**What is the purpose of this research?** I have been working on effective ways to incorporate the process of science into the chemistry curriculum and I plan to study the results of this teaching strategy on student comprehension. The results of this research will contribute to my understanding of best teaching practices.

**What will students do?** Students will participate in the usual curriculum for Conceptual Chemistry, but with added emphasis on the process of science. Students will complete the usual assignments, assessments and pre/post tests, as they would do normally. I will simply make copies of students' work for research purposes. I am asking for permission to use copies of student work for my research.

**What are the potential benefits?** I anticipate that my research will improve the quality of instruction that your child receives. I will report the results in my master's thesis so that other teachers and students can benefit from my findings.

**What are the potential risks?** There are no foreseeable risks associated with participating in this research. I will not open consent forms (where you say "yes" or "no") until after I have assigned final grades for the trimester. That way, I will not know who agrees to participate in the research until after grades are issued. In the meantime, I will save all written work. Later, I will analyze the written work only for students who have agreed to participate in the study and whose parents/guardians have consented.

**How will privacy and confidentiality be protected?** Students' names will not be reported in my master's thesis or in any other dissemination of the results of this research. Instead, the data will consist of class averages and samples of student work that will not include names. The only people who will have access to the data are me, my thesis committee at MSU, and the Institutional Review Board at MSU. The data will be stored on password-protected computers during the study and on password protected computers at MSU for at least three years after the study (in compliance with the law).

**What are your rights to participate, say no, or withdraw?** Participation in this research is completely voluntary. You have the right to say “no.” You may change your mind at any time and withdraw. If either the student or parent/guardian request to withdraw, the student’s information will not be used in this study. There are no penalties for saying “no” or choosing to withdraw.

**Who can you contact with questions and concerns?** If you have questions or concerns about this study, please do not hesitate to contact:

Ms. Courtney Lutz
Grand Ledge High School
820 N. Spring Street
Grand Ledge, MI 48837
lutzc@glcomets.net
(517) 925-5874

Dr. Merle Heidemann
118 North Kedzie Lab
Michigan State University
East Lansing, MI 48824
heidma2@msu.edu
(517) 432-2152 ext. 107

If you have questions or concerns regarding your child’s role as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if desired, MSU Human Research Protection Program at: **irb@msu.edu**

**How should I submit this consent form?** Please complete the attached form. Both the student and parent/guardian must sign the form. Please return with your student a form indicating interest either way. **<u>Please return this form to the drop-box in my classroom, room 404.</u>**

Sincerely,

Courtney Lutz

**Parents/guardians should complete this following consent information:**

I voluntarily agree to have ______________________________________ participate in this study.
(Student Name)

**Please check ONE of the two lines below:**

**Data:**

__________ I give Courtney Lutz permission to use data generated from my child’s work in this class for her research project. All data shall remain confidential.

__________ I do not wish to have my child's work used in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of participation in this research.

**Please check ONE of the two lines below:**

**Photography, audiotaping, or videotaping:**

__________ I give Courtney Lutz permission to use photos or videotapes of child in the class room doing work related to this thesis project. I understand that my child will not be identified.

__________ I do not wish to have my child's images used at any time during this thesis project.

_________________________________________ __________________________

(Parent Signature) (Date)

_________________________________________ __________________________

(Student Signature) (Date)

**Please return this form to the drop-box in my classroom, room 404 by September 12th.**

# APPENDIX 2

## TEACHER NOTES AND INSTRUCTIONS

## APPENDIX 2A
## NEXT GENERATION SCIENCE STANDARDS AND STUDENT LEARNING GOALS

Asking Questions and Defining Problems

- Formulate, refine, and evaluate empirically testable questions and design problems using models and simulations.
- Evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design. (HS-PS4-2)

Hypothesizing

- Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. (HS-PS1-5)
- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-PS1-2)

Thinking Critically

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS4-1)
- Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. (HS-PS4-4)

Presenting Information

- Communicate technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-PS4-5)

Learning Goals for Project (taken from NGSS)
Students will…

- Formulate, refine, and evaluate empirically testable questions. (HS-PS4-2)
- Apply scientific principles and evidence to provide an explanation of phenomena (hypothesis). (HS-PS1-5)
- Construct and revise an explanation based on valid and reliable evidence. (HS-PS1-2)
- Differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS4-1)
- Take into account possible unanticipated effects. (HS-PS1-5)
- Communicate technical information or ideas in multiple formats. (HS-PS4-5)

APPENDIX 2B
OUTLINE OF TEACHER ACTIONS

1. Instruct on method and scope of activity
2. Perform demonstration and ask students to observe
3. Allow 1 minute for students to record questions individually
    a. Elaborate on the core question – What's up with that?
    b. Make no assumptions
        i. if you immediately have an assumption, ask it in the form of a question
        ii. it may or may not be a correct assumption
        iii. we can then see if it's a testable question to investigate.
    c. Ask ANY question, even ones that may not be testable
        i. the purpose of the activity is to stimulate curiosity
        ii. we will deal with "evaluating" questions later
4. Record questions from individuals in front of class and discuss
    a. acknowledge that humans tend to wonder the same things – ask how many students had a particular question on their paper
    b. acknowledge that humans tend to wonder about a lot of things
    c. encourage curiosity and validity of questions, helping students build confidence
5. Group questions by type – some questions may appear different, but are actually asking the same thing
6. Choose one question to refine
    a. be clear about question
    b. descriptive or causation – both are ok
7. Allow students to record 3 possible answers to this question – explain that these answers are actually hypotheses
8. Record hypotheses from individuals in front of class and discuss
    a. keep asking "What else?"
    b. discuss the importance of looking for other explanations beyond the ones presented to you
9. Pick 1 hypothesis and ask students to predict what the evidence might looks like to support or contradict a hypothesis
    a. make a graph when appropriate
    b. doing work of interpretation can help sharpen a hypothesis
    c. using information about other possible hypotheses to discuss what variables to control for
10. Encourage students to revisit their original questions and add additional questions to the list now that they have more information - emphasize that in science the process is constantly repeating.
11. Collect and grade demo papers using modified rubric from pre/posttest assessments.
    a. each question worth 1 pt
    b. testable questions worth 2 pts
    c. hypothesis that addresses question 1 pt each
    d. predicted outcomes to support and to refute 1 pt each

    e. further questions 1 pt each

12. After returning papers, maybe just before the post-test, have students retrieve all old demo documents and compare their progress toward scientific thinking.
    a. Do they ask more questions?
    b. Are their questions deeper or more testable?

APPENDIX 2C
DEMONSTRATION OUTLINE

**Unit 1 – Acids and Bases** **Demonstration: Magic Pitcher**

This demonstration is designed to illustrate the effect of acids and bases on an indicator through the observation of color changes due to interactions of unknown substances. Repeated with known substances to offer more context.

**Unit 2 – Properties of Matter** **Demonstration: Iodine Clock reaction**

This demonstration is designed to illustrate a chemical reaction, but one in which the mechanism is not obvious. Repeated with varying concentrations of potassium iodate to generate different reaction times. When graphed, this data can be used to predict the rate of a reaction given a known volume of potassium iodate.

**Unit 3 – Gas Laws** **Demonstration: Crushing a Pop Can**

This demonstration is designed to illustrate the power and presence of gases all around us. By evacuating the can of air and then inverting and sealing it the atmospheric pressure is strong enough to collapse the aluminum of the can. Students may be familiar with the demonstration from previous years of science, but many will have forgotten the science behind it.

**Unit 4 – The Nucleus** **Demonstration: Cloud Chamber**

This demonstration is designed to allow students to see the alpha particles and beta particles emitted from a Thorium source (lantern mantle) to illustrate the presence of these particles in nature. Repeated with two different substances – an Americium source (from a smoke detector) and a non-radioactive rock.

**Unit 5 – Energy and Electrons** **Demonstration: Glow Stick in hot and ice water bath**

This demonstration is designed to illustrate that light can be generated by chemical energy in a glow stick. As well as the impact of heat energy on light intensity. This demonstration will present the greatest degree of prior knowledge out of the rest of the demos. The researcher wonders if this will allow students to generate more questions or if familiarity will stifle curiosity.

**Unit 6 – Periodic Trends** **Demonstration: Periodicity of Alkali Metals**

This demonstration is designed to illustrate the trend in reactivity of Group 1 metals as you go down the group. Lithium and sodium are used for comparison. Videos can be supplemented to show reactivity of more reactive elements.

# APPENDIX 3

## STUDENT ASSIGNMENTS AND ACTIVITIES

## APPENDIX 3
## GENERAL DEMONSTRATION RESPONSE FORM

DIRECTIONS: Observe the demonstration and respond to the following prompts

1. Record as many questions as you can think of in 60 seconds.

2. A testable question: ____________________________________________________________

3. Record at least 3 possible answers to the testable question in #2.

4. A testable hypothesis: ___________________________________________________________

5. If the hypothesis in #4 is supported by evidence, what data might we observe?

6. If the hypothesis in #4 is refuted by evidence, what data might we observe?

7. What other questions does this lead you to ask? (List any questions from #1 that still apply as well.)

# APPENDIX 4

## ASSESSMENT TOOLS

APPENDIX 4A
PRETEST/POSTTEST

DIRECTIONS: Complete the following assessment to the best of your ability. Answer all questions as fully as possible.

1. Define the term **hypothesis**.

2. What would it take for a **hypothesis** to be considered a **scientific theory** or **law**?

3. _______ On the line, record the letter of your choice regarding the **BEST** possible answer to the question, **What is science**? (if you cannot decide between two choices, you may write both – however, do not choose more than two)
    a. Science is a body of factual knowledge and truth
    b. Science is a diverse way of problem solving
    c. Science is scientists' tentative explanations for observations validated through rigorous inquiry processes.

4. Write all the **observations** you can make from the picture to the right. Do NOT record any **inferences**.

5. Generate as many **questions** as you can think of based on the picture to the right.

6. What is the **hypothesis** of this study in the article to the right?

7. What **evidence** do they provide to **support** their conclusions?

8. What **questions** could you ask for **clarification** or for **further study**?

9. List **THREE** or more **observations** as you can about the data set above from a *Science Magazine* article titled "Skills, education, and the rise of earnings inequality among the 'other 99 percent'."

10. Record **TWO** or more **questions** that you have about these data.
11. Read the following observation and record as many **questions** as you can think of, *at least* **THREE**, regarding this observation: *The chemical Luminol emits blue light energy when*

*reacted with hydrogen peroxide and water. The intensity of light is increased when a test tube containing this reaction is placed in hot water.*

12. Choose one of your most testable questions from #11 and write **TWO hypotheses** based upon the question.

_______ 1.
question #
2.

13. Choose a testable hypothesis from #12 and **predict** what evidence you might observe that would cause you to **conclude your hypothesis is false**.

_________
hypothesis #

14. Using the same hypothesis as in #13, **predict** what evidence you might observe that would cause you to conclude your **hypothesis is supported by your data**.

On a **scale of 1 to 5** please rate the following items, where 1= strongly disagree, 2= slightly disagree, 3 = neither agree nor disagree, 4 = slightly agree, 5 = strongly agree. **Circle** the number of your choices below.

| | | | | | | |
|---|---|---|---|---|---|---|
| a) | I am good at science. | **1** | **2** | **3** | **4** | **5** |
| b) | I am good at chemistry. | **1** | **2** | **3** | **4** | **5** |
| c) | I would voluntarily take another high school science class. | **1** | **2** | **3** | **4** | **5** |
| d) | I would voluntarily take a college-level science class. | **1** | **2** | **3** | **4** | **5** |
| e) | I am likely to go into a science-related profession. | **1** | **2** | **3** | **4** | **5** |

15. Please use your scores from the 5 items above to calculate the following:

a. Total of a) and b) __________ Total of c), d), and e) __________

Total of all responses a)-e) __________

(For a complete copy of the pretest/posttest, please contact the author at courtneylutz@gmail.com)

APPENDIX 4B
PRETEST/POTTEST SCORING RUBRIC

Table 1. A rubric containing the scoring guide used to evaluate pretest and posttest assessments

| Question Number | Rubric Scoring | | | | Student Score |
|---|---|---|---|---|---|
| | 3 points | 2 points | 1 point | 0 points | |
| 1 | | "An answer to a scientific question" | "An educated guess," "an if-then statement," or another previously-learned definition | An incorrect definition or no response | |
| 2 | | Time and an accumulation of evidence, testing by multiple researchers all reaching similar conclusions | Partially correct responses | No response, off topic or incorrect respnoses | |
| 3 | B or B & C | C | A & X | A | |
| 4 | More than 3 relevant* observations recorded | 3 relevant observations recorded some inferences are recorded | 1 or 2 relevant observations recorded, some inferences are recorded | 0 relevant observations recorded or all recorded responses are inferences | |
| 5 | 3 or more relevant questions posed | 3 or more questions posed, 2 or less questions are relevant | 1 or 2 questions posed, at least 1 is relevant | 0 relevant questions posed | |
| 6 | | Low dose aspirin will reduce the risk of pancreatic cancer. | Any mention of heart disease, other partially correct answers | No response | |

Table 1. Cont'd

| | | | | | |
|---|---|---|---|---|---|
| 7 | | Regular aspirin use lowered the risk of pancreatic cancer by 48%<br>1-3 yrs = 43%, 7-20 yrs = 56% | Partially correct responses | No response | |
| 8 | | Is aspirin preventing formation of new tumors?<br>Is aspirin helping immune systems fight new tumors? | 1 question but not two<br>A question not posed in the article. | No questions | |
| 9 | More than 3 relevant observations recorded | 3 relevant observations recorded | 1 or 2 relevant observations recorded | 0 relevant observations recorded | |
| 10 | 3 or more relevant questions posed | 2 relevant questions posed | 1 relevant question posed | 0 relevant questions posed | |
| 11 | 3 or more questions posed and at least one question is testable | 3 or more relevant questions posed<br>none are testable questions<br>or<br>1 or 2 relevant questions are posed and at least one question is testable | 1 or 2 relevant questions posed | 0 relevant questions posed | |
| 12 | 2 hypotheses are provided<br>and<br>Hypotheses are different answers to the same question<br>Both are testable | 1 or 2 hypotheses are provided<br>and<br>1 hypothesis is testable and answers the question, the other is not testable or does not answer the same question | Only 1 hypothesis is provided<br>and<br>Hypothesis does not answer the question or is not testable | No response | |

Table 1. Cont'd

| | | | | | |
|---|---|---|---|---|---|
| 13 | | Predicted data or observations are reasonable to expect and would cause the scientists to reject the hypothesis | Predicted data or observations are reasonable to expect but would support hypothesis, not refute it | Predicted data or observations are not reasonable to expect | |
| 14 | | Predicted data or observations are reasonable to expect and would support the hypothesis | Predicted data or observations are reasonable to expect but would not support hypothesis | Predicted data or observations are not reasonable to expect | |
| 15A | | 10 – 8 | 6 – 4 | 2 | |
| 15B | | 15 – 12 | 9 – 6 | 3 | |
| 15C | | 25 – 20 | 15 – 10 | 5 | |

*Relevant in this rubric simply means related to the figure or topic

| | |
|---|---|
| Total Score | |
| Confidence Score | |
| Curiosity Score | |
| Knowledge of Scientific Processes and Nature of Science Score | |

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REFERENCES


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