THE EFFECT OF INQUIRY IN A HIGH SCHOOL CHEMISTRY CLASSROOM ON STUDENT UNDERSTANDING OF THE NATURE OF SCIENCE AND THEIR ATTITUDE, CONFIDENCE, AND MOTIVATION

by

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

of

Master of Science

in

Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2016

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ACKNOWLEDGEMENT

I would like to thank Holderness School for making this graduate experience possible. They supported me financially, and allowed me to teach a Senior Thesis course, so that I'd be more informed for my graduate capstone. I would also like to thank Diana Paterson from the MSSE program for her endless support, answering my numerous questions at all hours of the day. Thanks to Heather Dietz for the statistical analysis assistance, especially in calculating normalized changes as an alternative to normalized gains. My capstone advisor, John Graves, was pivotal in the success of this project. Thanks, John, for all you did to keep my head above water, whether that meant scrutinizing numerous revisions of my paper, or encouraging me from afar in my outdoor pursuits when I looked to clear my head. Your support of the well-rounded student does not go unnoticed.

I am forever indebted to the Zabaleta family for their kindness, friendship, and hospitality during my summers in Bozeman. Not only did they provide delicious food and point me in the direction of long trail runs, but they opened their home to me. Through our long nightly conversations, they taught me the importance of adventure, open-mindedness, and diversity. I will certainly miss these evenings in Bozeman.

Finally, I owe a mountain of gratitude to my husband, Kurt Schuler, for all that he did to make this project and graduate degree a positive learning experience. He picked up all the balls that I couldn't juggle. Most importantly, at the end of long days for both of us, he listened, celebrating the excitement of my peaks and enduring the frustration of my troughs. Thanks, Kurt, for the encouragement, love, and companionship.

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ABSTRACT

Part of a science education is developing an understanding of the Nature of Science (NOS), the way in which scientific knowledge develops. The twenty-first century science classroom involves student engagement in inquiry learning, in which students investigate natural phenomena through practices utilized by scientists and engineers. This study investigated whether explicit instruction on the NOS and engagement in scientific inquiry investigations impacted student understanding of the way in which scientific knowledge develops. The study also investigated the effect on students' attitudes, confidence, and motivation with regards to scientific methodology. Through multiple formative assessments with constructive feedback, students most improved their confidence in and ability to design testable scientific research questions and corresponding investigative plans. The results indicated that students struggled applying their investigative research process to scientific methodology as a whole. This action research showed the importance of completing inquiry investigations in their entirety, in order for students to best learn the NOS.

INTRODUCTION AND BACKGROUND

I teach at Holderness School, an independent boarding school in Holderness, New Hampshire. The school is composed of grades 9 through 12 with an optional post-graduate year. The school educates about 275 students annually, making the faculty-student ratio 1 to 7. During the time of this study, there were 33 students in my three introductory chemistry classes. These students were a mix of mostly sophomores and juniors, with one senior. This was the first time these students had been introduced to high school-level chemistry, and these three introductory chemistry classes were the lower of two chemistry levels at Holderness. For the 2015-2016 academic year, school tuition was $54,100 for boarding students and $34,700 for day students. That being said, 40% of students received financial aid, totaling about $3.5 million in aid annually. During this academic year, Holderness School was composed of 16% international students and 10% domestic students of color. Fifteen percent of the students were day students (T. Pfenninger, personal communication, September 19, 2014). My introductory chemistry classes for this academic year were composed of 18% international students, 6% domestic students of color, and 12% day students. The school places high importance on academics and athletics, and all of our graduating seniors go to four-year colleges. Holderness is a tight-knit community fostered by small class sizes, family-style dinners, and faculty as coaches and dorm parents. This creates an atmosphere of respect between all community members: faculty, students, and staff alike.

Senior Thesis, once optional, became a graduation requirement at Holderness in the 2013-2014 academic year. The motto of this experiential second semester senior class

is *Question. Explore. Research. Share*. Holderness seniors develop their intellectual curiosity as they explore a topic of their choice. Unfortunately, there had been very few investigative science senior theses in Holderness history at the time of this research. Most science-related senior theses had involved topics that relied mainly on literature review, internships, or both. As the *Next Generation Science Standards* (NGSS) encourage teachers to incorporate inquiry investigations in their science classrooms, it is only realistic to assume that seniors will not choose to do laboratory theses unless they have had previous experience being autonomous in the lab. It is important to create classrooms where students do science in the laboratory just as scientists do work in their fields. I wanted to give my younger students this opportunity, with the hope that they would potentially pursue inquiry science investigations in their senior year.

At Bates College, my alma mater, all students are required to complete a thesis. As a biochemistry major, I chose to study the antibacterial and antioxidant properties of an Amazonian tree sap that I became familiar with during my study abroad in Ecuador. This thesis experience was the most formative of my educational journey thus far; it allowed me to pursue my own academic curiosity from start to finish with numerous peaks and pitfalls along the way. Most important was my ownership of the process.

In this action research project, I hoped to help my introductory chemistry students pursue their own scientific curiosities as they learned about the Nature of Science (NOS) and as they each created a testable scientific research question. My students learned how scientific knowledge is acquired. They asked questions and defined problems about the world around them. Then they planned an investigation in order to find answers. Because

they were exploring their own interests, I hoped that this project would help improve my students' attitudes, motivation, and confidence in investigative science. Looking ahead, I hoped that they would have the opportunity to carry out their science inquiry plan or a new science lab investigation as a Senior Thesis topic in their final year at Holderness.

These experiences and reflections led to the formation of my focus statement, *Will chemistry students' understanding of the NOS be impacted by explicit NOS instruction and engagement in scientific inquiry investigations, specifically the process of formulating a scientific research question and an investigative plan?* In addition, the following sub-questions were addressed, 1) *How do NOS instruction and engagement in inquiry affect students' abilities to write testable scientific research questions?* 2) *Will engagement in scientific inquiry practices affect students' attitudes, confidence, and motivation with regard to scientific methodology? Additionally, will engagement of underclassmen in scientific inquiry result in more investigative science senior theses at Holderness School?*

CONCEPTUAL FRAMEWORK

The *National Science Education Standards* called for action in the science classroom at the turn of the twenty-first century. These standards stressed the importance of inquiry in learning science. They defined inquiry as the process of observing and describing one's surroundings, asking questions, planning and undergoing experiments, developing explanations, and communicating findings (National Research Council [NRC], 1996). Inquiry is driven from student experiences, and it aims to make sense of

natural phenomena. Inquiry learning helps students develop critical thinking and scientific reasoning skills.

In 2013, the *Next Generation Science Standards* (NGSS) emerged from the *National Science Education Standards*. The NGSS was based on the NRC's report in 2011 titled *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012). The NGSS detailed eight science and engineering practices in which all students should engage by the end of secondary school: (1) asking questions and defining problems, (2) developing and using models, (3) planning and carrying out investigations, (4) analyzing and interpreting data, (5) using computational thinking, (6) constructing explanations and designing solutions, (7) engaging in argument from evidence, and (8) obtaining, evaluating, and communicating information. The NGSS emphasized the need for student understanding of the development of scientific knowledge, the work of scientists and engineers, and the applications of science and engineering in the natural world. Another goal was to increase student curiosity, motivation, and appreciation for science and engineering. The NGSS stressed the importance of assessing students' understanding of science content through their ability to solve real-world problems using the eight science and engineering practices. Science inquiry is a large piece of these practices (NGSS Lead States, 2013).

Research shows that it is important to continually utilize science and engineering practices in the classroom in order to establish the classroom as an inquiry environment. Inquiry begins with the teacher instilling inquisitiveness in their classroom. It is important to design lessons that engage students in critical thinking and argumentation.

Wonder can only be infused into the science classroom if teachers see their students as members of the greater scientific community. This is a community of questions, arguments, contradictions, surprise, curiosity, excitement, failures, and not knowing. Teachers must shift the attitude of their students away from knowledge as absolute. Instead, the teacher must validate the students as knowers, thinkers, and learners who are able to construct meaning from the natural world (MacKenzie, 2001). Questions and discussions surrounding "What if?", "How?", and "Why?" allow for inquiry and exploration. A successful inquiry classroom discussion uncovers more questions than it answers. The teacher's role is to facilitate this discussion and create a positive learning environment (Foster & Lemus, 2015).

Science inquiry is often divided into four levels along a continuum of ownership, responsibility, and self-discovery (Llewellyn, 2013; Banchi & Bell, 2008). Llewellyn's lowest level of inquiry, called *demonstrated inquiry*, involves teacher ownership of all parts of the inquiry activity. An example of this type of inquiry is a discrepant event. In Llewellyn's *structured inquiry*, the teacher is responsible for asking the question and devising the procedure, but the students gather and analyze the data. Bell and Banchi separate this type of inquiry into two levels: *confirmation inquiry* and *structured inquiry*. In *confirmation inquiry*, the results are already known and data collection skills are the primary focus. Often, this inquiry follows the content lecture. In Bell and Banchi's *structured inquiry*, the teacher is still responsible for presenting the question and the procedure, but the students use the results as evidence to explain a phenomenon. In both Llewellyn's and Bell and Banchi's third level, called *guided inquiry*, the teacher poses

the question, and the students are responsible for planning the procedure and collecting the data. In Llewellyn's *student-initiated inquiry*, synonymous to Bell and Banchi's *open inquiry*, the students are responsible for all parts of the inquiry process. This highest level of inquiry is the most self-directed, requiring significant scientific reasoning and critical thinking skills.

In open inquiry, students design their own question to study, often referred to as an essential question. Essential questions have been defined as having seven characteristics: open-ended, intellectually stimulating, recurring, contains important transferable ideas, requires higher-order thinking, sparks additional questions, and requires justification. There are many methods for developing essential questions. One method is to form a question surrounding the key nouns and verbs in the NGSS or other standards. Another method is to generate an essential question surrounding a desired understanding, desired either by the student or the teacher. Essential questions can also be derived from broad, overarching questions or from possible misconceptions (McTighe & Wiggins, 2013).

In an effort to create a curriculum that focused on open inquiry with questioning, critical and scientific thinking, a biology curriculum called *Biomind* was created for Israeli high school students. In the curriculum, four models were presented for the ways in which Israeli high school students developed an open inquiry investigation plan from inquiry questions during a biology lesson. The *Sequential Model* begins with the student developing a question. As results are obtained, more questions are formulated one-at-a-time, with the inquiry plan developing after a series of three questions and subsequent

conclusions. In the *Semi-Sequential Model*, students start with a question, and the results dictate the formation of two questions which can be observed in parallel. In the *Parallel Model*, the students develop three parallel inquiry questions, which allow for a thorough understanding of the problem as a whole at the project's onset, and therefore the inquiry plan is able to be in place at the beginning of the project. In the *Semi-Parallel Model*, students begin with two parallel questions, the conclusions from which allow them to formulate the third question. The *Parallel Model* provides the most certainty and is the least dynamic, while the *Sequential Model* provides the least certainty and is the most dynamic. While the subject matter can dictate the appropriate model type, the researchers found that the highly curious students tended to choose the model that provided the least certainty and the most dynamic inquiry (Zion & Sadeh, 2007).

These various models show the dynamic process required in the transition between questions and results. Because authentic inquiry is constructivist in nature, it requires an active process. Constructivism is the theory that learning is an evolutionary process in which learners constantly adapt incoming information to fit their preconceptions as they reconstruct their understandings (Llewellyn, 2013).

In one study, students began the inquiry process by rating example research questions as *good*, *okay*, or *bad*. These parameters were specifically defined by their ability to lead the researcher to an improved understanding. The students then created their own scientific questions following a series of guidelines that involved observations, logic, and curiosity. They were also given statements and questions to consider as they

designed their own authentic questions. Finally, students self-assessed their questions using the *good*, *okay*, and *bad* three-category scale (Foster & Lemus, 2015).

An eight-category taxonomy was developed to evaluate the quality of student-written scientific questions. The lowest category incorporated questions that did not make logical sense. The highest category incorporated questions that contained part of a research hypothesis. The authors believed that the highest three categories were researchable. The practice of critiquing and classifying students' questions led to higher-level questions by the end of the semester (Marbach-Ad & Sokolove, 2000).

A different model involved a progression through the inquiry levels throughout the year. The objective was to introduce inquiry in a biology laboratory without undergoing time-consuming and costly curricular changes. In one of the approaches, students wrote questions at the beginning and end of the lab exercises. The other approach involved a progression from small-scale guided inquiry labs to open inquiry experiments. Most students chose independent experiments that related to a post-lab question from a previous mini-experiment. Working in pairs, the students were provided guidelines and due dates for each piece of the experiment (Polacek & Keeling, 2005).

Student ownership is crucial in inquiry-based learning for the acquirement of scientific reasoning skills. One study focused on the formation and refinement of students' initial inquiry investigation questions in a high school biology class, while simultaneously trying to preserve student ownership of their questions. Question refinement is a long, interactive process involving authentic resources, peer discussion,

and teacher feedback. Moreover, teacher guidance must diminish as the project progresses in order to maintain student ownership (Lombard & Schneider, 2013).

Various case studies have shown positive results from inquiry learning. A ten-year study showed the importance of more inquiry and less content. As the level of inquiry in biology lab exercises increased, content knowledge increased and student opinions improved. Although the content learned was specific to a few topics, the critical thinking skills and fundamental knowledge was applicable to a broad range of science topics (Luckie et al., 2012). Other research showed increased motivation and conceptual understanding after an inquiry investigation; although they found that conceptual understanding was linked more to self-confidence than to motivation (Patrick & Yoon, 2004). Another study found that higher levels of inquiry in a chemistry laboratory favored more exploratory, rather than procedural, approaches. Student interactions also involved more idea propositions and less low-level question and answer engagements (Xu & Talanquer, 2013).

Not all studies shed a positive light on inquiry learning. One study reported on both the teacher and student perspectives of inquiry learning in two high school science classrooms. Although the lessons had focus and purpose, the students developed a narrow view of inquiry with low-level thinking and repetitive processes. The content, lab practices, and assessment requirements dictated by the national standards produced mechanistic learning in rather closed lab investigations, failing in an attempt to give students experience in authentic experimental inquiry and design (Hume & Coll, 2008). Other research further showed that student engagement in open inquiry does not

necessarily result in an improved understanding of the Nature of Science (NOS) (Salter & Atkins, 2014).

Various techniques have been used to assess student content knowledge, motivation, and confidence in science inquiry classrooms. Many of these techniques involve pre- and post-inquiry lab assessments. Qualitative techniques include interviews, surveys, observations, teacher journaling, and videotaping. Quantitative techniques include summative assessments, Marbach-Ad and Sokolove's (2000) taxonomy of questions, and Dillon's (1984) classification of research questions, which involves categorization of questions as first-order, second-order, or third-order based on the number and relationships of variables involved (Donham, Heinrich, & Bostwick, 2010; Foster & Lemus, 2015; Hassan & Yarden, 2012; Luckie et al., 2012; MacKenzie, 2001; Patrick & Yoon, 2004).

METHODOLOGY

The purpose of this study was to determine the effect of student engagement in open inquiry on their understanding of the Nature of Science (NOS) and their attitudes, confidence, and motivation toward using scientific methodology. Thirty-three high school students, who made up three introductory chemistry classes, participated in this study. The treatment period began mid-fall with instruction on experimental design and data analysis. Instruction included designing experiments on paper and working with example data sets, as well as designing guided inquiry experiments to investigate in the laboratory. The investigations included analysis of acquired data. NOS instruction also included explicit teaching of significant figures in measurements and dimensional

analysis, skills needed for data collection and analysis. The treatment period culminated mid-winter with an open inquiry investigation. In this independent investigation, students formulated a testable scientific research question, completed a literature review, and designed an investigative plan to answer their question. The research methodology for this project received an exemption by Montana State University's Institutional Review Board, and compliance for working with human subjects was maintained (Appendix A).

To collect data on student understanding of the NOS, the Nature of Science Pre- and Post-Test was implemented (Appendix B). Part A of this test included two standardized ACT Science Reasoning problems in which students were tested on their ability to analyze data and answer subsequent multiple choice questions. Part B included multiple choice questions on experimental design. Part C of the NOS Pre- and Post-Test included open-ended questions that tested students' understanding of the way in which scientific knowledge develops. The data collected from parts A and B were analyzed for normalized gains and were reported in box and whisker plots. The Nature of Science Pre- and Post-Test Part C Rubric was used to analyze Part C (Appendix C). This rubric detailed whether or not students understood certain aspects of the NOS (Lederman et al., 2002). The data was quantified and totaled, with *1* indicating a student's NOS understanding and *0* indicating a lack of understanding. The total scores were graphed and were analyzed for normalized gains.

Student Post-Treatment Interviews were used to qualitatively assess students' understanding of the NOS, students' processes of writing and refining scientific research questions, and students' attitudes, confidence, and motivation in using scientific

methodology (Appendix D). All students were interviewed from each class, in order to maximize diversity. The data was analyzed for themes and was used to support other findings.

The Experimental Design Assessment was used to assess students' abilities to write scientific research questions and design an investigative plan (Appendix E). This assessment was administered multiple times throughout the treatment period as students designed their open inquiry investigation. The Experimental Design Assessment Rubric was used to grade the Experimental Design Assessment (Appendix F). Both the assessment and rubric were adapted from Schaefer (2014). The total score was tallied for each student during each administration of the assessment. The results were analyzed for normalized gains, and changes over the treatment period were analyzed graphically. The Wilcoxon Signed Rank Test was employed to determine if there was a significant difference between the initial and final implementations of this assessment.

The Taxonomy of Student Questions Rubric was used to assess students' abilities to write testable scientific research questions (Appendix G). The rubric, adapted from the taxonomy presented by Marbach-Ad and Sokolove (2000), contained eight categories from low to high levels of critical thinking. The rubric was used multiple times as students wrote and adapted their research question for the open inquiry investigation. Normalized gains were calculated for each student, and changes over the treatment period were analyzed graphically. The Wilcoxon Signed Rank Test was used to determine if there was a significant difference between the first and last iterations of the research question.

The Pre- and Post-Treatment Likert Survey was used to determine students' attitudes, confidence, and motivation with regards to scientific methodology (Appendix H). The questions asked students to rate their enjoyment or interest as well as their confidence and motivation in various aspects of the scientific inquiry investigation process. The students responded with *Strongly Disagree* (1), *Disagree* (2), *Neutral* (3), *Agree* (4), or *Strongly Agree* (5). The Likert data was tallied quantitatively. The results were analyzed for normalized changes, following the method outlined by Marx and Cummings (2007). According to this method, if the post rating was greater than the pre rating, normalized change was calculated by: (post-pre)/(5-pre). If the pre rating was greater than the post rating, normalized change was calculated by: (post-pre)/pre. If the post rating equaled the pre rating, the normalized change was zero, unless the student's pre and post ratings were both *Strongly Disagree* or were both *Strongly Agree*. In these cases, the student's data was removed from the data set. The Wilcoxon Signed Rank Test was utilized to determine if there was a significant difference between pre- and post-treatment. The changes from pre- to post-treatment were also analyzed graphically. The final question of the survey was the Pre- and Post-Treatment Likert Question on Senior Thesis. This question asked students to rate their potential interest in undergoing an investigative science Senior Thesis in their last semester at Holderness School. The students were also given an opportunity to explain their response in a textbox. The data for this Likert question was quantified according to the method above. Normalized changes were calculated for all participants, and the changes from pre- to post-treatment

were analyzed graphically. The data collection instruments are summarized in the triangulation matrix below (Table 1).

Table 1
Data Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
Primary Question: Will student understanding of the NOS be impacted by explicit NOS instruction and engagement in inquiry investigations?	Multiple Choice Data Analysis and Experimental Design Questions on NOS Pre- and Post-Test (Parts A and B, respectively)	Open-ended Understanding NOS Questions on NOS Pre- and Post-Test (Part C)	Student Post-Treatment Interviews
Secondary Question: Will students' abilities to write scientific research questions be impacted?	Experimental Design Assessment	Taxonomy of Student Questions Rubric	Student Post-Treatment Interviews
Secondary Question: Will student attitudes, confidence, and motivation in using scientific methodology be impacted?	Pre- and Post-Treatment Likert Survey	Student Post-Treatment Interviews	Pre- and Post-Treatment Likert Question on Senior Thesis

DATA AND ANALYSIS

The multiple choice sections of the Nature of Science (NOS) Pre- and Post-Tests assessed proficiency in two areas: data analysis skills on ACT-like questions (Part A) and experimental design skills (Part B). The results indicated that the average percent increase from before treatment to after treatment for data analysis and experimental design was 3.64% and 12.73%, respectively (N=33). Although the median only increased for the experimental design section of the test, from 60% in the pre-test to 70% in the post-test, the scores tightened for both sections, seen in the standard deviation (Figure 1). To better interpret the change in these multiple choice test scores, normalized gains were calculated. The average normalized gain for the experimental design section of the test was 12%, meaning that, on average, the treatment caused the students to understand 12% more of that which they didn't originally understand about designing experiments. The average normalized gain for the data analysis section of the NOS test, the component containing ACT-like questions, was negative 14%, indicating lower scores on the post-test compared to the pre-test. Although visually from the graph there appeared to be no change, the distribution of the scores from pre- to post-test corresponded to this low normalized gain. This minimal improvement in experimental design and data analysis skills was reflected in the interview. When students were asked what parts of the learning process were most helpful in developing an understanding of the ways in which scientific knowledge is acquired, few students mentioned the experimental design process and no students mentioned the data analysis process.

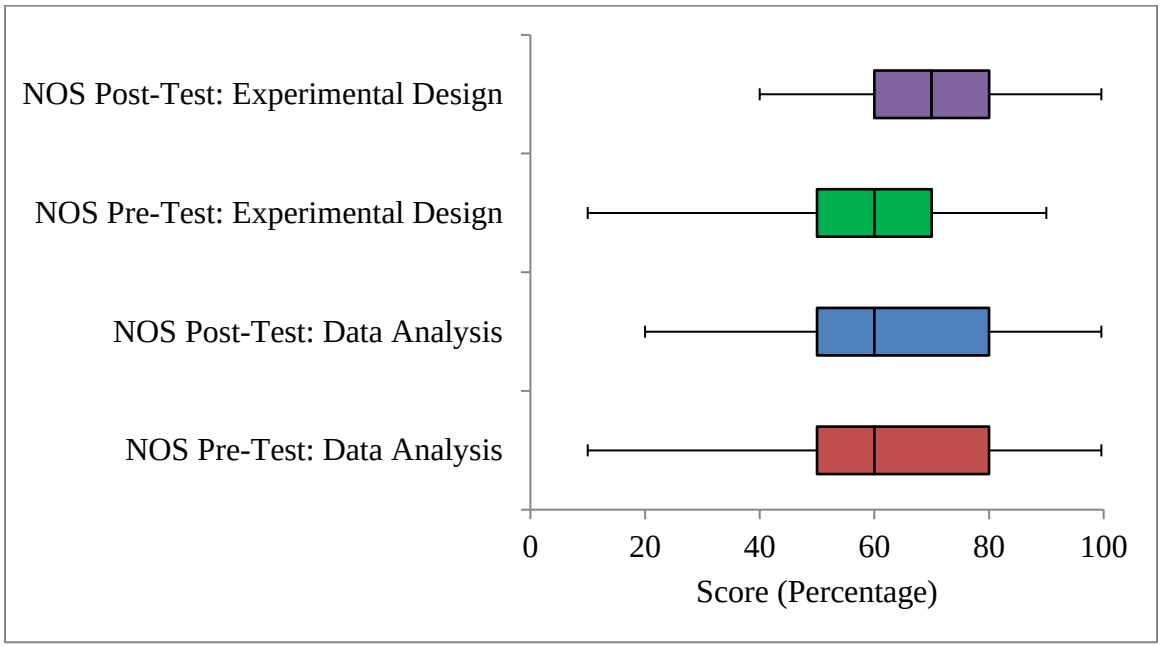


Figure 1. Score distributions of the NOS Pre- and Post-Tests on Part A data analysis skills and Part B experimental design skills, (*N*=33).

Part C of the NOS Pre- and Post-Tests assessed student understanding of the NOS. The average normalized gain for student understanding of the NOS as a whole was 27%. When the students were asked which components of the learning process were most helpful in understanding the NOS, one student responded, "The most helpful was researching past experiments because that way we could see how scientists conclude and prove hypotheses." Another student replied, "The research was eye opening for me in this project. I didn't know how long it took for scientists to gather information and that it could take years of experimenting in some cases."

In analyzing each NOS aspect individually in the NOS Pre- and Post-Test Part C Rubric, the number of students who understood controlled variables, independent variables, dependent variables, and formulation of a research question with a cause and effect relationship between variables each increased by over 30% (Figure 2). The number

of students who understood that evidence supports rather than proves scientific claims increased by 24%. Student understanding that creativity permeates scientific processes and that science is a mixture of objective and subjective approaches both declined from pre-test to post-test. These findings are consistent with the interview data. When the students were asked if they used creativity or subjectivity during their independent investigations, most students replied affirmatively; however, in providing examples, they all referred to creativity or subjectivity only in choosing their topic. For example, one student said, “I used creativity by choosing what I love to do, sports, and that made my experiment easier.” Other students, like this one, still held misconceptions, “Using personal opinions and feeling would not benefit science.”

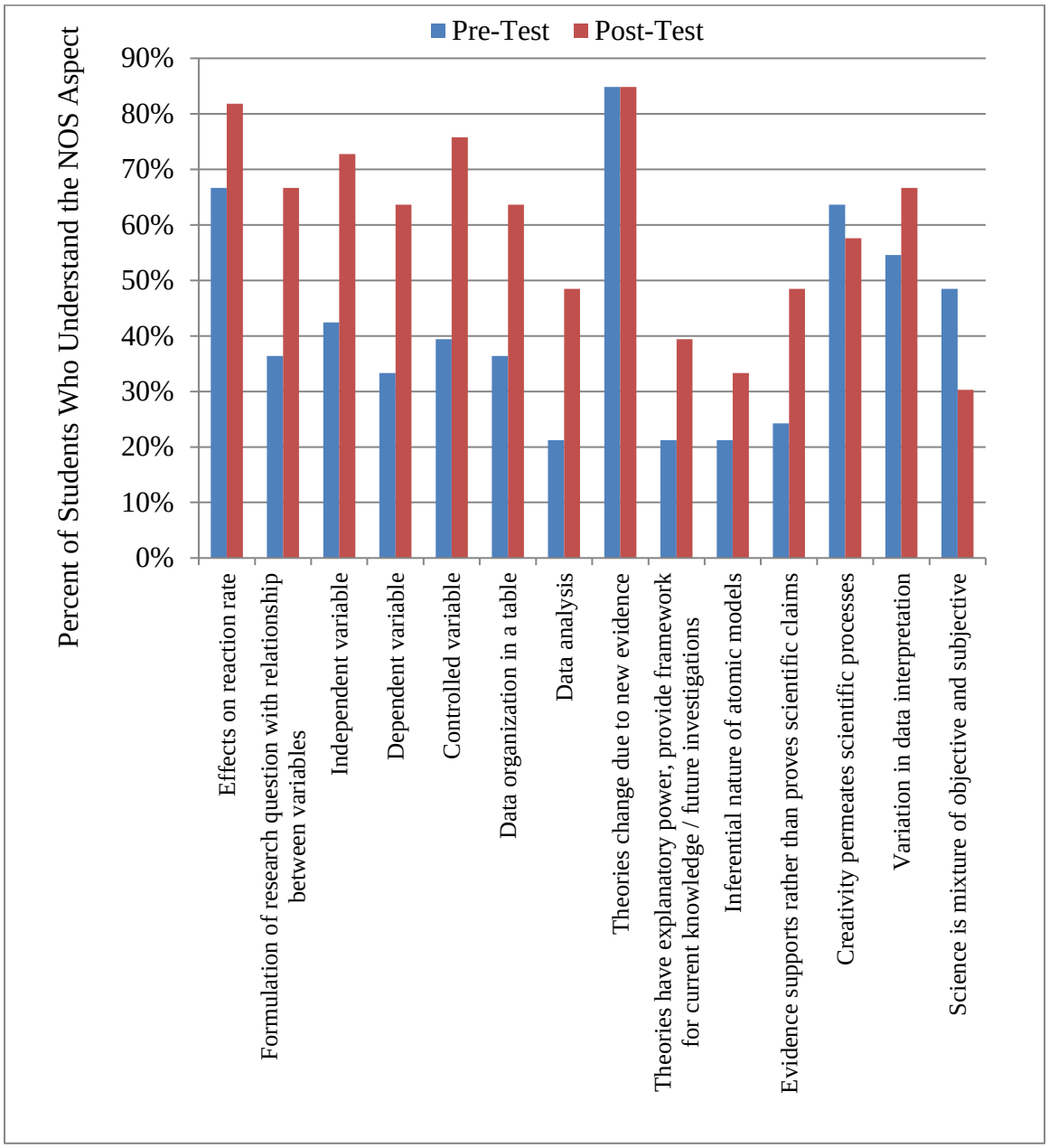


Figure 2. Score distribution for each aspect of the NOS Pre- and Post-Test Part C section on NOS understandings, (*N*=33).

Results from the Experimental Design Assessment showed that students' ability to design their own experiments improved on average over the treatment period (Figure 3). The average normalized gain of 57% showed moderate improvement from the first

administration of this assessment, Assessment #1, to the last administration, Assessment #3.This was verified with the Wilcoxon Signed Rank Test. This statistical test reported a p-value of < 0.0001, thereby rejecting the null hypothesis and stating that there was significant difference between the median scores of the initial and final Experimental Design Assessments. This finding was consistent with the interview responses. When asked what part of the learning process was most helpful in learning the ways in which scientists acquire knowledge, one student replied, "I think designing the experiment was helpful because I was able to see what scientists do to come up with ideas." Another student said that the most helpful part was "figuring out ways for the experiment to be more successful."

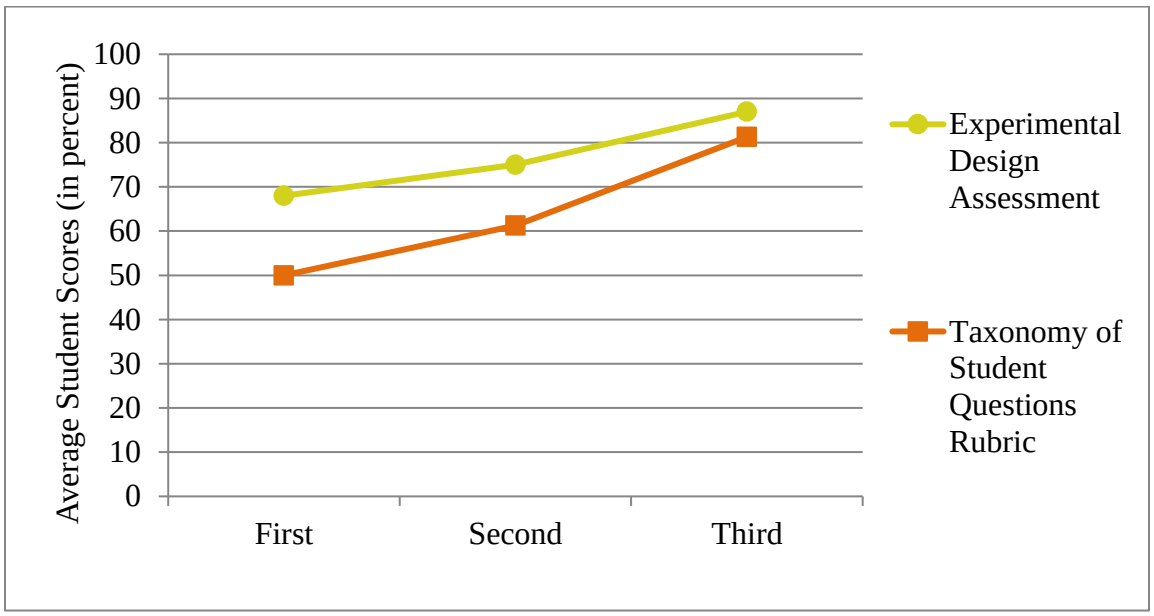


Figure 3. Average score progressions on the Experimental Design Assessment and the Taxonomy of Student Questions Rubric, each administered three times over the treatment period, (*N*=33).

Results from the Taxonomy of Student Questions Rubric showed that students' ability to formulate a testable scientific research question improved on average over the

treatment period (Figure 3). The average normalized gain of 59% showed a moderate improvement from their initial attempt at writing a testable research question to the final iteration of their research question. This significant statistical difference was supported by a p-value of < 0.0001 from the Wilcoxon Signed Rank Test. Improvement shown by the Taxonomy of Student Questions Rubric was consistent with interview responses. When asked what parts of the learning process were most helpful, one student replied, "Re-doing our questions a number of times helped me to get better with my research, which helped me narrow down my research." When asked how students refined their research question, one student said, "I looked at your comments and kept building off what you wrote."Another student said, "I thought more about the independent and dependent variables, and how they contribute to my research question."

The Pre- and Post-Treatment Likert Survey assessed students' attitude, confidence, and motivation in using scientific methodology. The results are shown graphically below, with the Likert response of *neutral* centered horizontally to show the change in positive responses to the right in green hues and negative responses to the left in red hues (Figure 4). While the average normalized change for confidence and comfort in the investigative research process from pre- to post-treatment was 15%, the normalized changes for the specific components of writing testable research questions and designing experiments to test a hypothesis were highest, at 24% and 29%, respectively. This is consistent with the findings from the Taxonomy of Student Questions Rubric and the Experimental Design Assessment, which showed marked improvement in these areas. A Wilcoxon Signed Rank Test was used to analyze the paired Likert confidence data from

pre- to post-treatment. The statistical test showed p-values higher than 0.20 for most of the Likert responses on confidence, meaning that there was no statistical difference in student confidence from pre- to post-treatment. The p-value was 0.072 for the survey question that asked students to rate their confidence in their ability to write a testable scientific research question. This still showed no statistical change in confidence over the treatment period. This disagreed with the interview data. When asked about their confidence in specific areas of the research process, many students mentioned the improvement in their ability to design a research question. One said, "I feel most confident in developing a good research question." With a p-value of 0.0093, the only statistically significant improvement in student confidence was in their ability to design a scientific experiment to test their hypothesis. This specific improvement agreed with the interview data. When asked if their ability to conduct a scientific investigation from scratch had improved, 97% of students responded affirmatively (N=33). One student elaborated, "Yes, I think that with a good layout and scientific research, I've come a long way." When asked about their confidence specifically, one student replied, "Understanding the topic gave me my confidence."

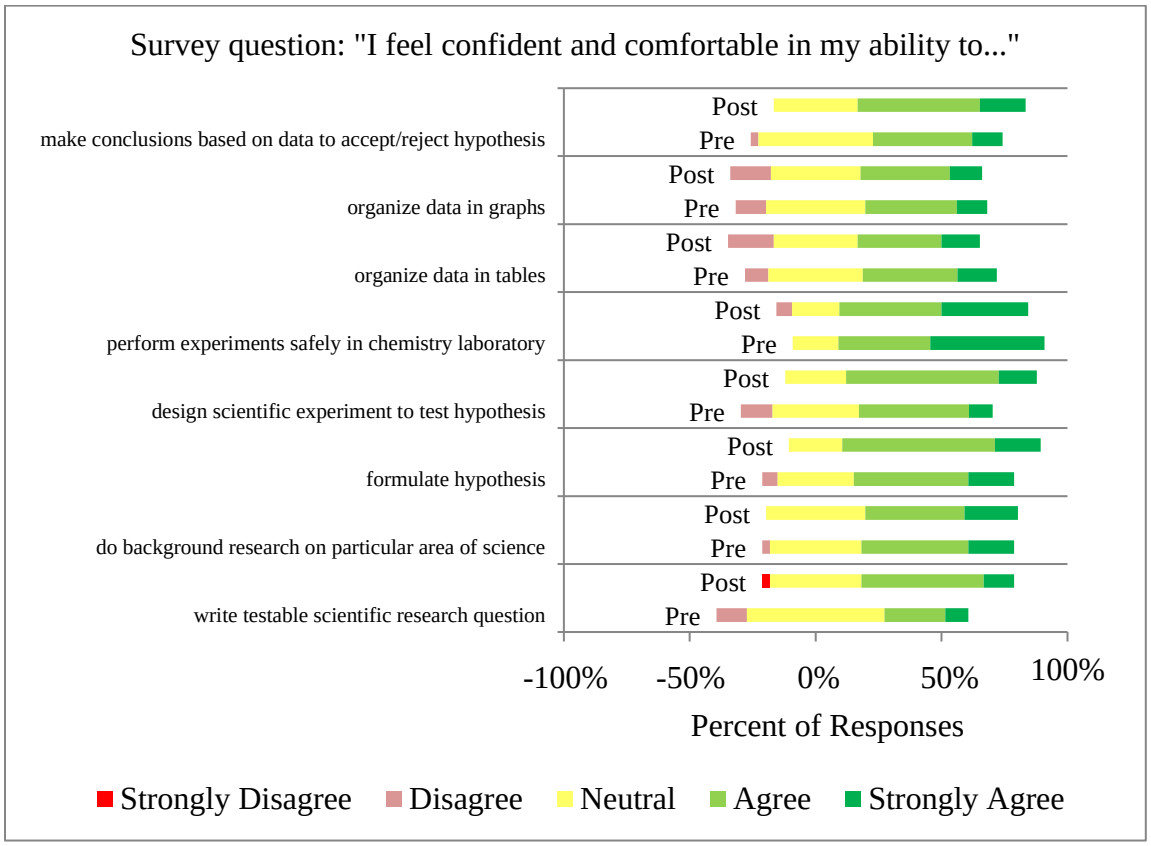


Figure 4. Results on confidence and comfort from the Pre- and Post-Treatment Likert Survey, (*N*=33).

The Pre- and Post-Treatment Likert Survey also assessed students' enjoyment and interest in the investigative research process. The average normalized change from pre- to post-treatment for all questions surrounding enjoyment and interest was 15% (Figure 5). With normalized changes of 25% and 28%, respectively, open inquiry investigations most increased student interest in designing scientific experiments to test hypotheses and performing chemistry experiments in the laboratory. Student interest in doing background science research improved the least, with a normalized change of 4%. A Wilcoxon Signed Rank Test was used to analyze the paired Likert data on interest from pre- to post-treatment. The statistical test showed p-values much higher than 0.05 for all of the Likert

responses on interest, meaning that there was no statistical difference in student interest in any part of the investigative research process from pre- to post-treatment. The interview data was inconclusive in terms of level of interest, but when asked what parts most interested students, it was clear that "being able to study or focus on something that interests you," as one student put it, was valuable in the research process. Another student mentioned the "freedom of doing exactly what I wanted to do," seeing the personal benefit of the research. One student who lacked this freedom said, "Honestly, I'm not sure if I found any of it enjoyable or very interesting. I chose it because my mom said it would be a good topic." On the other hand, the freedom to choose a topic didn't necessarily equate to a higher level of interest. When asked about their choice of topic and progression of level of interest during the research process, one student said, "At first, I thought my topic was really interesting, but after working on it for this long, I started getting a little tired and felt myself being redundant with the information."

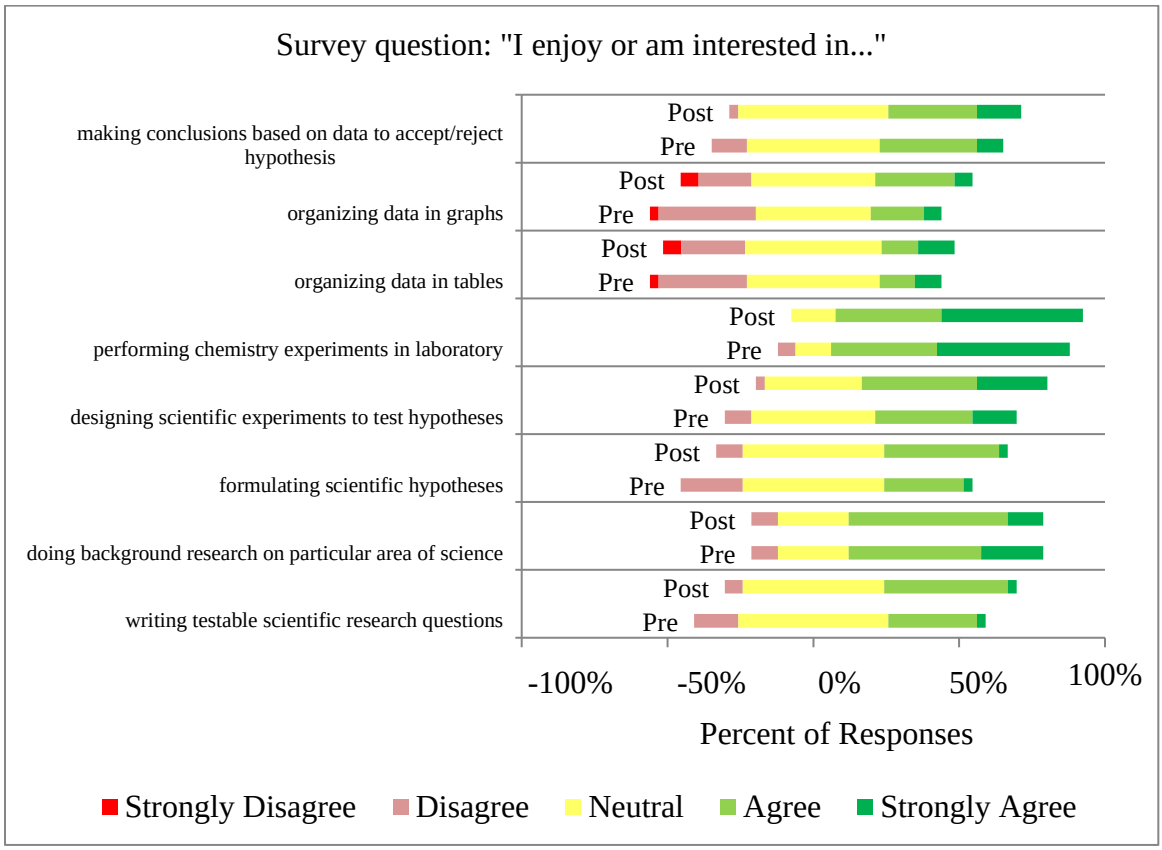


Figure 5. Results on enjoyment and interest from the Pre- and Post-Treatment Likert Survey, (*N*=33).

This insignificant change in interest and enjoyment in investigative science was also seen on the final question of the Pre- and Post-Treatment Likert Survey, which asked students the degree to which they planned to do an investigative science Senior Thesis in their final year at Holderness (Figure 6). The average normalized change was a slim 1.5% for this Likert question. The p-value of 0.55 from the Wilcoxon Signed Rank Test verified that students' Senior Thesis plan did not change as a result of the treatment. The students were also asked to elaborate on this Likert survey question. One student, who chose *neutral* in the pre-treatment survey, said, "I put neutral because I'm not sure what I'm going to do for my Senior Thesis, therefore I don't have a specific answer." In the

post-treatment survey, the same student chose *disagree* and said, “I do not want to do a scientific Senior Thesis because that is not what I am most interested in.” Conversely, a student who chose *disagree* in the pre-survey stated, “I am planning on doing my Senior Thesis on something involving sports.” However, this student’s reply was more positive in the post-survey, in that they chose *agree* and stated, “I am interested in doing my Senior Thesis on the anatomy of the body.” Although the Wilcoxon Signed Rank Test showed no difference from pre- to post-treatment in students’ Senior Thesis plan, during the interviews, 97% of students affirmed that their ability to conduct a scientific investigation from scratch improved as a result of the treatment. When asked what their fears were about doing an investigative science Senior Thesis, one student replied, “My fear would be not having enough prior knowledge to know how to conduct an actual experiment if I had to.” Another student said that they would be afraid of “something going wrong during the experiment.” Similarly, another student responded, “I wouldn’t have professional advice, and feel that I would most likely conduct the experiment incorrectly.”

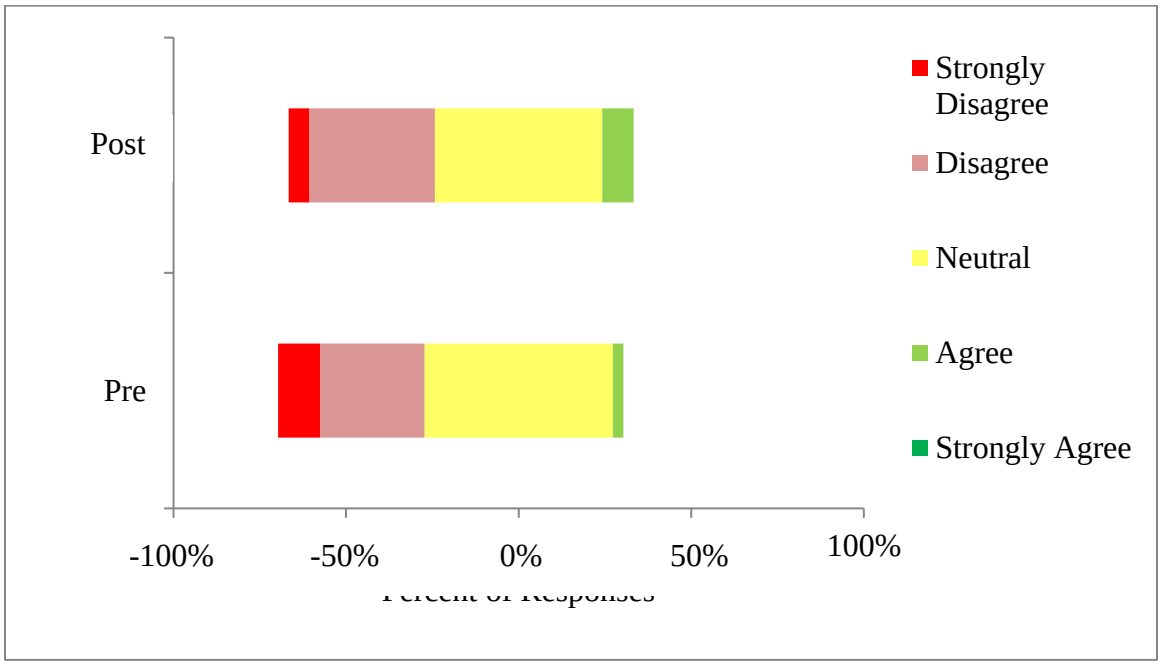


Figure 6. Survey question: "I plan to do an investigative science Senior Thesis, which will involve working in a laboratory to explore a question that I pose about the natural world," (*N*=33).

INTERPRETATION AND CONCLUSION

The goal of this action research project was to increase students' understanding of the Nature of Science (NOS) through inquiry investigations. With more engagement and autonomy in the laboratory, another goal was to improve students' ability to write testable scientific research questions and their attitude, confidence, and motivation. Numerous quantitative and qualitative data collection methods were employed, and multiple data analysis tools were applied.

From the Interviews, Pre- and Post-Treatment Likert Survey, and Taxonomy of Student Questions Rubric, it was obvious that students most improved their ability to formulate a testable scientific research question over the treatment period. Their confidence in this component of scientific methodology also improved. When students

began to formulate their research questions, their investigations lacked direction, so determining their independent and dependent variables was challenging. As students dove into the experimental design process, their research questions became more focused. In examining examples from the rubric as a class, students also learned to incorporate just enough background information in their question to give the question a foundation in the scope of science. Because students completed multiple iterations of their research question, with feedback from the teacher each time, it was not surprising that the average normalized gain was 59%.

From the Interviews, Pre- and Post-Treatment Likert Survey, and Experimental Design Assessment, students' improvement in their ability to design a scientific investigation was also evident. Like with their research questions, students revised their scientific investigations multiple times, with feedback from the teacher on each assessment. Because of this consistent feedback, it was not surprising that the average normalized gain on the Experimental Design Assessment was 57%. With a p-value of 0.0093 on the Wilcoxon Signed Rank Test, this was also the only portion of the Pre- and Post-Treatment Likert Survey that showed statistically significant improvement in confidence over the treatment period. Students also expressed this confidence in the Interviews.

The primary question of this research focused on student understanding of the NOS. The Pre- and Post-Test Part C Rubric showed that improvement in NOS understanding was limited to the knowledge of controlled variables, independent variables, dependent variables, and formulation of a research question with a cause and

effect relationship between the variables. In reality, these variables are more associated with experimental design than with the NOS, or of science as a way of knowing. Students showed no improvement in understanding the fundamentals of the NOS from the Appendix C rubric, like *creativity permeates scientific processes* (Figure 2). Even though students used creativity, for example, in their experimental design process, few students connected their process to the development of scientific knowledge on a larger scale.

This disconnect was also seen in Part B of the NOS Pre- and Post-Test, which assessed students' experimental design skills. Although students showed significant improvement on the Experimental Design Assessment, they did not improve their Part B scores. They were unable to apply the skills learned in designing their open inquiry investigation to hypothetical experiments on the multiple choice test. There was also no improvement on Part A of the NOS Pre- and Post-Test, which assessed students' data analysis skills. This was not surprising, because the treatment period involved little data analysis. For example, the open inquiry investigation terminated with the student development of the procedure and data table. Because students did not actually carry out their investigations, they did not have the opportunity to work with acquired data. In order to expect improvement on the Part A ACT-like questions, students would need to either complete their investigations or work with sample data sets in the future.

Although the Pre- and Post-Treatment Likert Survey showed little improvement in students' confidence, the Interviews and personal observations were more telling. Confirmed by the Wilcoxon Signed Rank Test, students' confidence in experimental design improved the most. Because significant time was spent on this portion of the

investigative process, it was not surprising that their confidence improved. As students became more comfortable with the design process, they took more ownership of their experiments. As their teacher, it was a joy to watch them become more autonomous, self-directed learners. During the Interviews, 97% of students said that their ability to conduct an open inquiry investigation had improved (*N*=33). Many students mentioned that because they had the freedom to choose their topic, they felt knowledgeable, and this gave them confidence. Freedom and self-directed learning are fundamental to scientific inquiry, as well as to Holderness School's Senior Thesis program.

The Pre- and Post-Treatment Likert Survey showed no improvement in student attitude or motivation with regards to scientific methodology. Although some students mentioned their heightened interest due to the freedom in choosing their topic, from personal observation, it seemed like the level of interest decreased for many students over the treatment period. For some students, this seemed due to the lack of initial interest in their topic. Other students chose a topic related to their favorite sport. Although they were motivated by their interest in the particular sport, they later realized that designing an experiment around their sport was more challenging than they had expected. Many students also realized that in order to design an experiment that was within their level of knowledge, the experiment became rather elementary. This reduced their interest in their topic, thereby separating the motivational aspect from the scientific aspect, which could have a lasting negative impact on their attitude towards scientific methodology.

The Pre- and Post-Treatment Likert Survey final question about Senior Thesis was a great indicator of students' attitude and motivation during this project. On one

hand, for many sophomores, choosing a topic for a senior project was far too distant to contemplate. On the other hand, conducting the open inquiry investigation seemed to only expose more inadequacies and concerns of the students, rather than allow them to acquire necessary skills, confidence, and motivation. The lack of follow-through in conducting the experiments was likely a large piece of this problem.

VALUE

Open inquiry investigations allow students the freedom to explore their own curiosities scientifically. For many students, this autonomy piques their interest in the subject matter. During this project, some students designed thoughtful, thorough investigations that spurred more questions. Other students designed simple experiments that stemmed from lackluster research questions. Another set of students got bogged down in the complexity of their investigation. In all cases, the students learned about the Nature of Science (NOS) as they engaged in scientific methodology. Failure and revision were both commonplace in this project, much as they are in the scientific community. Although this may have deterred students from choosing an investigative science Senior Thesis topic, I think the open inquiry investigation was valuable as part of their high school science education. As many as 80% of my students won't take a science course beyond high school (K. Mattingly, personal communication, April 30, 2015). Because of this, it's important for them to develop pertinent science skills and an understanding of the NOS in my classroom.

In the past, this inquiry investigation was just a library research project, synonymous with a literature review. Adding the investigative design component allowed

the students to take ownership of the project, choosing a topic that likely interested them more. In reading students' final papers, in which they combined their research question, as the title, with their literature review, materials, procedure, and data table, I was so proud of my students. Most of them effectively provided the background information for their experiment with the literature review, giving a clear picture of what the scientific community already knew about their topic. It is so important for students to understand the historical basis for contemporary scientific investigations, and they don't often have the opportunity to do this with typical lab reports in science classrooms.

When implementing this project in the future, I hope to have the students conduct their investigations. Because students designed experiments in all science disciplines, requiring tools that we did not have, and many involving animal test subjects, I would need to restrict the parameters of their investigations. Unfortunately, this might negatively affect their attitude and motivation. If I moved this open inquiry investigation to the end of the school year, then at least students would be able to choose a topic from the entirety of the curriculum. Another benefit would be that this would also help reinforce the chemistry content learned that year.

In looking at the treatment period more closely, minor adjustments could help the students be better learners and scientific researchers. For example, I could introduce the NOS instruction and inquiry investigation by dissecting a published scientific article. Intentionally analyzing the journal article would give students a clearer picture of the components of a professional paper, with foreshadowing to their final product at the culmination of the project. Additionally, after doing significant library research, some

students realized that it was too challenging to design a viable, high school-level experiment around their topic. Unfortunately, they had already spent significant time developing and revising their research question. Constraining the areas of research, as mentioned above, would help alleviate this problem. It would also help to intentionally introduce the project as an investigative research project that is supported by the relevant literature, rather than a library research project that flows into an experiment. Although seemingly minor, this adjustment in how I introduce and scaffold the project makes a big difference in students' understanding of how scientific knowledge develops.

Similarly, I need to better implement the Claims, Evidence, Reasoning (CER) model throughout the year in the chemistry classroom. To scaffold this, I need to teach it early in the fall, using a real scientific investigation as an example. Then, students need to use this model in all laboratory investigations, making claims from their observations, providing reliable evidence to support their claims, and using reasoning to explain how the evidence supports their claims. As a classroom facilitator, I also need to use this model when students make a hypothesis or display their knowledge, always asking for them to provide the *evidence* to back their claim. Claims, evidence, and reasoning are important components of the scientific practice of *engaging in argument from evidence* (NRC, 2012).

This project will continue to be modified as these ideas are implemented over a number of years. Each implementation will provide important insight for the following year. As science education leans toward inquiry learning, and as I look to give students more autonomy in laboratory investigations, this insight will be valuable for improving

upon my teaching and my students' learning. I appreciate my students' flexibility and grit in a system that is rapidly trying to place ownership of learning on the students themselves. Science also demands these same qualities, as the visiting professional scientist mentioned to the students at the onset of this project. Unfortunately, I cannot say that this project sparked student interest in future scientific research, but again, I'm not done yet!

As for me, this action research project certainly sparked my interest in future action research. It showed me that student feedback is the most important factor in curriculum design and adaptation, and as such, should be gathered numerous times throughout the school year. Each student enters the classroom with a unique learning style and preconceived knowledge. By the time they reach my classroom, they've already been in the formal education system for at least a decade. They have much input to give. Not only does soliciting student feedback improve my teaching, but it also improves my students' metacognitive skills as they think about the way in which they learn. As scientific inquiry puts students in command of their learning, action research indirectly puts curriculum design in students' laps as well. Finally, we have a teaching process that focuses on the learner.

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APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD EXEMPTION

MONTANA
STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
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MEMORANDUM

TO: Alexandra Disney and John Graves

FROM: Mark Quinn, Chair Mark Quinn CQ

DATE: November 10, 2015

RE: *"The Effect of Open Inquiry in a High School Science Classroom on Student Understanding of the Nature of Science"* [AD111015-EX]

The above research, described in your submission of November 10, 2015, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

X (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

X (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

___ (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

___ (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.

___ (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

___ (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

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

APPENDIX B

NATURE OF SCIENCE PRE- AND POST-TEST

<u>Part A</u>: This part contains two "Problems" with subsequent multiple choice questions.

Problem 1:

Passage II

Two studies were done in a lab to investigate how the amount of carbon dioxide (CO_2) in a volume of gas affects the rate at which the temperature of the gas increases.

Two identical glass tanks with airtight lids (Tanks A and B) were opened, and the same quantity of black sand was added to each. To heat the gas in the tanks, a lamp with a 150-watt lightbulb was placed at one end. A thermometer was set up at the other end so that the bottom of the thermometer would be in the gas and 5 cm above the top of the sand (see diagram).

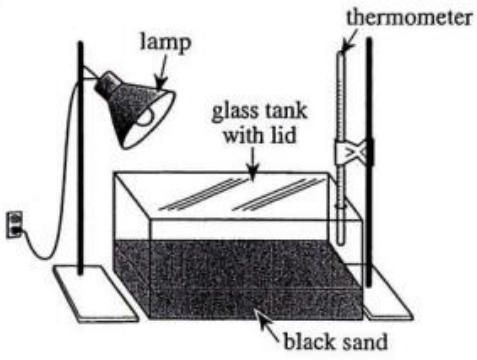


diagram of setup for a tank

Study 1

The lid of Tank A was closed after the sand was added. Five minutes (min) later, the temperature of the gas in the tank was recorded. (The pressure of the gas in the tank equaled atmospheric pressure.) Immediately afterward, the lamp was turned on, and the temperature of the gas in the tank, in degrees Celsius (°C), was recorded every 30 seconds (sec) for 10 min. The results are shown in Figure 1.

Study 2

The lid of Tank B was closed after the sand was added. Through a tiny hole made in the lid, all the gas that was present was removed from the tank and replaced with 100% CO_2 at atmospheric pressure. Immediately after the CO_2 was added, the hole was sealed with an airtight material. Five min later, the temperature of the gas in the tank was recorded. Immediately afterward, the lamp was turned on, and the temperature of the gas in the tank was recorded every 30 sec for 10 min. The results are shown in Figure 2. (Note: The light received by Tank B was of the same brightness and at the same angle as the light that had been received by Tank A.)

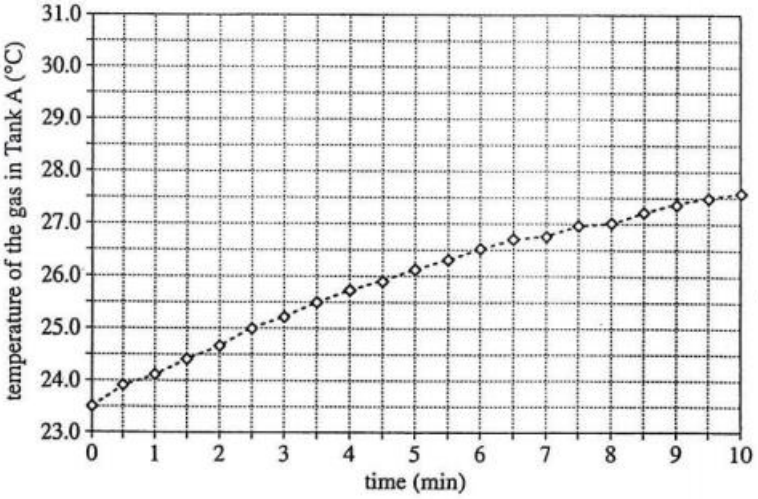


Figure 1

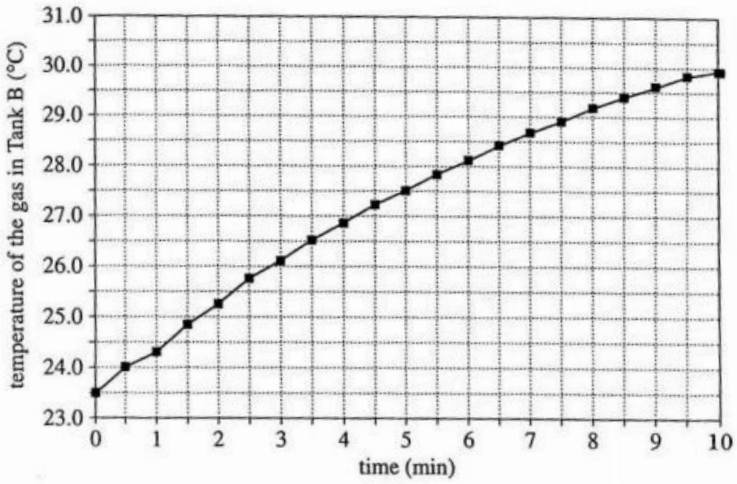


Figure 2

1. According to the results of Study 1, the temperature of the gas in Tank A at 0 min was:
    a. 22.0°C
    b. 22.5°C
    c. 23.0°C
    d. 23.5°C

2. According to the results of Studies 1 and 2, the temperature of the gas in Tank A at 10 min was most nearly the same as the temperature of the gas in Tank B at:

a. 5 min
b. 7 min
c. 9 min
d. 11 min

3. The temperature of the gas in which tank increased more quickly, and why?
    a. Tank A, because the gas in that tank contained less CO_2 than did the gas in Tank B.
    b. Tank A, because the gas in that tank contained more CO_2 than did the gas in Tank B.
    c. Tank B, because the gas in that tank contained less CO_2 than did the gas in Tank A.
    d. Tank B, because the gas in that tank contained more CO_2 than did the gas in Tank A.

4. Suppose that what occurred in Tanks A and B after the lamps were turned on was intended to model how the temperature of Earth's atmosphere changes as the amount of CO_2 in the air changes. What would have been represented by the black sand and what would have been represented by the lamp's light?

	black sand	lamp's light
a.	Earth's surface	Earth's atmosphere
b.	Earth's surface	Sun's energy
c.	Earth's atmosphere	Earth's surface
d.	Earth's atmosphere	Sun's energy

5. Were Studies 1 and 2, together, designed to determine if the brightness of light received by a volume of gas affects the rate at which the temperature of the gas increases?
    a. No, because only Tank A had a light shining on it.
    b. No, because the brightness of light received was the same for both tanks.
    c. Yes, because only Tank B had a light shining on it.
    d. Yes, because the brightness of light received was different for each task.

Problem 2:

Students performed the following experiments to determine the density of common plastics.

Experiment 1

A dry 100 mL graduated cylinder was placed on an electronic balance and *tared* (the balance was reset to 0.000 g). H_2O was added to the graduated cylinder until a certain mass was obtained. Ethanol was added to the graduated cylinder until the volume of liquid was 50.0 mL. The density of the liquid was then calculated. The procedure was repeated with different amounts of ethanol and H_2O (see Table 1).

Table 1

Liquid	Mass of H_2O (g)	Mass of ethanol (g)	Total mass (g)	Density (g/mL)
1	0	39.67	39.67	0.793
2	10.24	32.43	42.67	0.853
3	19.79	25.23	45.02	0.900
4	35.42	12.47	47.89	0.958
5	49.96	0	49.96	0.999

Experiment 2

A known mass of potassium iodide (KI) was dissolved in a known mass of H_2O. A dry 100 mL graduated cylinder was placed on the balance and tared. The solution was added to the graduated cylinder until the volume was 50.0 mL. The density of the liquid was then calculated. The procedure was repeated with different amounts of KI and H_2O (see Table 2).

Table 2

Liquid	Mass of H_2O in solution (g)	Mass of KI in solution (g)	Mass of solution in graduated cylinder (g)	Density (g/mL)
6	97.66	7.36	52.51	1.05
7	95.41	15.52	55.70	1.11
8	94.38	20.68	57.53	1.15
9	92.18	29.08	60.63	1.21
10	87.77	41.31	64.64	1.29

Experiment 3

A solid plastic bead was placed at the bottom of a sample of each of Liquids 1–10 from Experiments 1 and 2. If the bead stayed at the bottom, "S" was recorded in Table 3. If the bead rose, "R" was recorded in Table 3. The procedure was repeated for various plastics.

Table 3

Plastic	Liquid									
	1	2	3	4	5	6	7	8	9	10
Polybutylene	R	R	R	R	R	R	R	R	R	R
VLDPE	S	R	R	R	R	R	R	R	R	R
LDPE	S	S	S	R	R	R	R	R	R	R
HDPE	S	S	S	S	R	R	R	R	R	R
PA-11	S	S	S	S	S	R	R	R	R	R
PA-6	S	S	S	S	S	S	S	R	R	R
Polycarbonate	S	S	S	S	S	S	S	S	R	R
PVC	S	S	S	S	S	S	S	S	S	S

6. In Experiment 1, the density of ethanol was found to be:
   a. less than 0.793 g/mL.
   b. 0.793 g/mL.
   c. 0.999 g/mL.
   d. greater than 0.999 g/mL.

7. Based on the results of Experiments 1-3, the density of PA-11 is most likely:
   a. less than 0.793 g/mL
   b. between 0.853 g/mL and 0.958 g/mL
   c. between 0.999 g/mL and 1.05 g/mL
   d. greater than 1.11 g/mL

8. A plastic bead was tested as in Experiment 3 using Liquids 1-4. Which of the following is **not** a plausible set of results for the plastic?

Liquid			
1	2	3	4

   a. R R R R
   b. R R S S
   c. S S R R
   d. S S S S

9. In Experiments 1 and 2, the students tared the graduated cylinder in each trial so they could more easily determine:
    a. the mass of the substances added to the graduated cylinder.
    b. the density of the graduated cylinder.
    c. when the total volume of the added substance was equal to 50.0 mL.
    d. when all of the KI was dissolved in the H_2O.

10. A student claimed that polycarbonate is more dense than PA-6. Do the results of Experiments 1-3 support this claim?
    a. No, because in Liquid 8, polycarbonate stayed at the bottom and PA-6 rose.
    b. Yes, because in Liquid 8, polycarbonate stayed at the bottom and PA-6 rose.
    c. No, because in Liquid 8, polycarbonate rose and PA-6 stayed at the bottom.
    d. Yes, because in Liquid 8, polycarbonate rose and PA-6 stayed at the bottom.

<u>Part B</u>: multiple choice—circle the most appropriate answer

11. Which of the following questions is legitimate for science to consider?
    a. When is religion better than philosophy?
    b. Is competition good or bad?
    c. How many seals can a killer whale consume per day?
    d. Which type of orchid flower is most attractive?

12. How does a scientist confirm data?
    a. By consulting with an expert in the field
    b. By checking calculations for error
    c. By observing that repeating the experiments yields similar results
    d. By making sure that technicians follow procedures properly

13. In an experiment, what is affected by the independent variable?
    a. Dependent variable
    b. Internal variable
    c. Independent variable
    d. External variable

14. What factors can be changed in an experiment?
    a. Controls
    b. Constants
    c. Standards
    d. Variables

15. Based on your observations, you suggest that the presence of water could accelerate the growth of bread mold. This is:
    a. A conclusion
    b. A hypothesis
    c. An experiment
    d. An analysis

16. Consider the research question, "Does changing the volume of a gas affect the gas pressure?" Identify the independent and dependent variables in the experiment.
    a. Volume is the dependent variable, and pressure is the independent variable.
    b. Volume is the independent variable, and pressure is the dependent variable.
    c. Both volume and pressure are the independent variables.
    d. More information about the experiment must be given to determine the variables.

17. Which of the following states the correct arrangement of data in a scatter plot?
    a. Dependent variable data is plotted as X, independent variable data is plotted as Y.
    b. Independent variable data is plotted as X, dependent variable data is plotted as Y.
    c. Time is always plotted as X.
    d. The variable with the smaller values is plotted as X.

18. Which of these experimental questions would produce data best displayed on a bar graph?
    a. How does solubility of oxygen gas change as temperature of water changes?
    b. What is the effect of increased molecular mass on the boiling point of hydrocarbons?
    c. What is the average height for each of four different varieties of corn plants?

d. How does a swimmer's body temperature change as he/she completes a swim in cold water?

19. Which of the following statements is true?
    a. Scientists report numerical values with an exact number of digits that express the required degree of accuracy.
    b. Scientists do not report units after numerical quantities because the appropriate unit can be assumed.
    c. Scientists round all numerical values to the hundredths place, or two decimal places.
    d. The scientific method, followed by all practicing scientists, is an investigative process with a rigid order in which all scientific experiments are conducted.

20. The purpose of a literature review is to:
    a. Establish a theoretical framework for the topic
    b. Define key terms
    c. Identify studies that support the topic
    d. Define/establish the area of study
    e. All of the above

<u>Part C</u>: short answer—complete the following questions using paragraphs with complete sentences

21. Your class has been directed to investigate factors that affect the rate of reaction when Alka-Seltzer reacts with vinegar. Design an experiment to investigate one variable that might affect the rate of reaction. Write an appropriate research question and identify the independent, dependent, and controlled variables for the experiment.

22. Students in physics class are asked to find the relationship between the length of a pendulum (string with a weight at the bottom) and the time it takes for one pendulum swing. Reorganize the data in the new table below to show a possible relationship between the variables, and state the relationship, if any, between the independent and dependent variables.

Group Number	Length of String (m)	Angle of Release (degrees)	Mass at End of String (g)	Time for One Swing (s)
Group 1	0.25	60	500	1.00
Group 2	1.00	60	500	2.01
Group 3	0.50	60	500	1.42
Group 4	1.50	60	500	2.46
Group 5	0.30	60	500	1.10

New Table:

23. After scientists have developed a theory (e.g. atomic theory), does the theory ever change? If so, why might it change? If you believe that theories do change, explain why we bother to teach scientific theories. Defend your answer with examples.

24. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

25. Scientists perform experiments/investigations when trying to solve problems. Other than the planning and design of these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain your answer and provide examples if appropriate.

26. Some astronomers believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?

Resources:
Part A: Adapted from “ACT Science Test: Explore-05A” (2015) and “ACT Science Test: ACT-64E-Practice” (2015)
Part B: Adapted from Schaefer (2014) and Trout (2012)
Part C: Adaped from Lederman et al. (2002) and Trout (2012)

APPENDIX C

NATURE OF SCIENCE PRE- AND POST-TEST PART C RUBRIC

NOS Test Question Number	**NOS Aspect: Does the student understand…?**	**Pre-Test**	**Post-Test**
21	Effects on reaction rate	☐	☐
	Formulation of research question with cause/effect relationship between variables	☐	☐
	Independent variable	☐	☐
	Dependent variable	☐	☐
	Controlled variable	☐	☐
22	Data organization in a table	☐	☐
	Data analysis	☐	☐
23	Theories change due to new evidence	☐	☐
	Theories have explanatory power and provide a framework for current knowledge and future investigations	☐	☐
24	Inferential nature of atomic models	☐	☐
	Evidence supports rather than proves scientific claims	☐	☐
25	Creativity permeates scientific processes	☐	☐
26	Variation in data interpretation	☐	☐
	Science is a mixture of objective and subjective	☐	☐

Adapted from Lederman et al. (2002)

APPENDIX D

STUDENT POST-TREATMENT INTERVIEWS

*Participation in these interviews is voluntary, and you can choose not to answer any question or stop at any point. Participation, non-participation, or specific responses will not affect your numerical or effort grade in this course.

Primary Question:

1. Did you think about the scientific method or practices when designing your research question and investigation? If so, provide examples.

2. What parts of this learning process were most helpful in learning the ways in which scientists acquire knowledge?

3. Did you use any creativity or subjectivity when engaging in independent investigations? If so, provide examples.

First Secondary Question:

4. What is the most difficult or challenging part of writing a good scientific research question?

5. How did you refine your research question during the process?

Second Secondary Question:

6. Attitude: What was the most enjoyable or interesting part of the independent investigation? Why? Provide an example(s).

7. Confidence: What part of the research question and experimental design process are you best at? (ie. What is your biggest talent?) What part of the process do you need to improve on?

8. Motivation: Why did you choose your independent research topic? How did your level of interest change as the independent investigation proceeded?

9. Senior Thesis:
    a. Do you feel that your ability to conduct a scientific investigation from scratch has improved?

    b. What are your fears about doing an investigative science Senior Thesis, in which you would explore your own question about the world in the laboratory or field?

APPENDIX E

EXPERIMENTAL DESIGN ASSESSMENT

Identify the following:	Points
1. Research Question:	
2. Independent Variable:	
3. Dependent Variable:	
4. Controlled Variables:	
5. Hypothesis (must include cause and effect relationship between variables):	
6. General Procedure:	
7. References with Citations:	
Teacher Comments:	**Total:**

Adapted from Schaefer (2014)

APPENDIX F

EXPERIMENTAL DESIGN ASSESSMENT RUBRIC

Category	1	2	3	4
Research Question	The question cannot be tested scientifically.	The question is testable but is vague or too broad.	The question is testable and specific but parts need clarification.	The question is well-written, specific, and scientifically testable.
Independent Variable	Variable is incorrectly identified and improperly defined.	Variable is incorrectly identified or improperly defined.	Variable is correctly identified but not properly defined/described.	Variable is clearly and properly defined/described, including all relevant details.
Dependent Variable	Variable is incorrectly identified and improperly defined.	Variable is incorrectly identified or improperly defined.	Variable is correctly identified but not properly defined/described.	Variable is clearly and properly defined/described, including all relevant details.
Controlled Variables	The controlled variables are vague or do not pertain to the research question.	The controlled variables are incomplete.	The controlled variables are complete but lack clear specificity.	The controlled variables are complete and clearly specified.
Hypothesis with Cause and Effect Relationship Between Variables	Hypothesis does not mention independent variable and/or dependent variable.	Hypothesis does not draw any relationship between independent and dependent variables.	Hypothesis contains improperly stated cause and effect relationship between variables.	Hypothesis contains clearly stated cause and effect relationship between two variables.
General Procedure	The general procedure is vague or does not pertain to the research question.	The general procedure is incomplete.	The general procedure is complete but lacks clear specificity needed to be replicable.	The general procedure is complete and clearly specified so that it can be replicated.
References with Citations	No references are included.	References do not properly pertain to the question.	One or more references are included but without citations.	Two or more references are included and contain citations.

Adapted from Schaefer (2014)

APPENDIX G

TAXONOMY OF STUDENT QUESTIONS RUBRIC

Your Research Question:

- Category 0: Questions that do not make sense logically or grammatically or are based on basic misunderstandings or misconceptions.

- Category 1a: Questions about a simple definition, fact, or idea, that could be easily looked up online or in a textbook. (ex. "What does the first law of thermodynamics mean?")

- Category 1b: Questions about a more complex definition, fact, or idea that is explained fully online or in a textbook. (ex. "What does it mean when it says atomic orbitals are quantized?")

- Category 2: Ethical, moral, philosophical, or sociopolitical questions. (ex. "If carbon monoxide is so deadly, why are there no carbon monoxide detectors throughout the dorm halls?")

- Category 3: Questions for which the answer is explained by a scientific law. (ex. "Why do the mass of the products equal the mass of the reactants?")

- Category 4: Questions in which the student seeks more information than is available online or in a textbook. (ex. "What causes an airbag to inflate during a car crash?")

- Category 5: Questions resulting from extended thought and synthesis of prior knowledge, often preceded by a summary, a paradox, or something puzzling. (ex. "An online source says the shorter the wavelength, the more energetic the light. I know that blue light in fires is hot, but UV light has shorter wavelengths. Does this mean that fire could release energy in the UV range?")

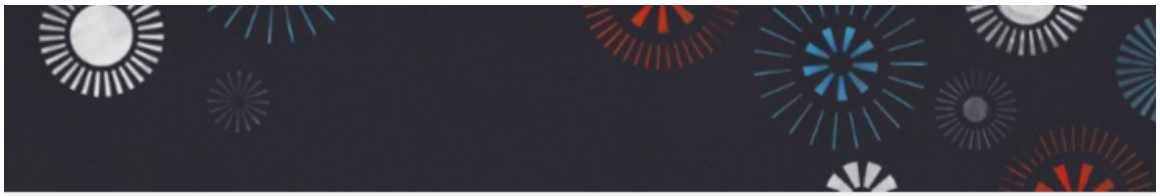
- Category 6: Questions, which result from extended synthesis of prior knowledge, contain within them the core of a research hypothesis and independent and dependent variables. (ex. "I have heard that the Gulf of Mexico has a large dead zone. What correlation is there, if any, between fertilizer runoff from farms on the Mississippi River and oxygen levels in the Gulf? Could bacteria be creating hypoxic zones when they break down superfluous organic matter?")

Teacher Comments:

Adapted from Marbach-Ad and Sokolove (2000)

APPENDIX H

PRE- AND POST-TREATMENT LIKERT SURVEY



Nature of Science Likert Survey

This survey will assess your attitude, confidence, and motivation about your ability to think like a scientist before and after the Nature of Science (NOS) unit. Participation in this survey is voluntary and you can choose not to answer any question or stop at any point. Neither participation nor non-participation will affect your numerical grade or effort grade in this class. Your specific responses or lack of responses will not affect your numerical grade or effort grade in this class.
For each question below, indicate how much you agree or disagree with each statement by choosing the appropriate option.

Your username (**adisney@holderness.org**) will be recorded when you submit this form. Not **adisney**? Sign out

I enjoy or am interested in writing testable scientific research questions.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I enjoy or am interested in doing background research on a particular area of science.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I enjoy or am interested in formulating scientific hypotheses.

- Strongly Disagree

- Disagree
- Neutral
- Agree
- Strongly Agree

I enjoy or am interested in designing scientific experiments to test my hypotheses.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I enjoy or am interested in performing chemistry experiments in the laboratory.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I enjoy or am interested in organizing data in tables.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I enjoy or am interested in organizing data in graphs.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I enjoy or am interested in making conclusions based on the data, thereby accepting or rejecting the original hypothesis.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I feel confident and comfortable in my ability to write a testable scientific research question.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I feel confident and comfortable in my ability to do background research on a particular area of science.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I feel confident and comfortable in my ability to formulate a hypothesis.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I feel confident and comfortable in my ability to design a scientific experiment to test my hypothesis.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I feel confident and comfortable in my ability to perform experiments safely in the chemistry laboratory.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I feel confident and comfortable in my ability to organize data in tables.

- Strongly Disagree

- Disagree
- Neutral
- Agree
- Strongly Agree

I feel confident and comfortable in my ability to organize data in graphs.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I feel confident and comfortable in my ability to make conclusions based on the data, thereby accepting or rejecting the original hypothesis.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I plan to do an investigative science senior thesis, which will involve working in a laboratory to explore a question that I pose about the natural world.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Please explain your answer to the question above.

Send me a copy of my responses.

Submit

Never submit passwords through Google Forms.