A STUDY ON SHIFTING SCIENCE CURRICULUM TOWARD INQUIRY BASED PRACTICES

by

Chelsea Mahota Agee

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

of

Master of Science

in

Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2021

DEDICATION

I dedicate this work to my two children, Icina and Alexander Holmes for being patient with me during this process and making me laugh even when I was stressed. I'd also like to thank my mom, Helen Fairrie Galey and her life partner, George Andrew Corrette III for their endless support and encouragement. They have been patient with me over years of pursuing higher education and it has not been without sacrifice.

ACKNOWLEDGEMENTS

I am grateful to my students who made this work possible. They give me something to look forward to every day. Many thanks to my close friend, Sara Yager, who helped me get stronger (both physically and mentally) by being my hiking partner over the past year. It has made the process of finishing this work easier and more enjoyable. I cannot begin to express my deepest gratitude to my geology professors from Keene State College, Dr. Steven Bill and Dr. Peter Nielsen, who instilled within me a thirst for critical thinking, persistence within academics, not to mention a love of geology. Many thanks to my two colleagues, Monica Foley and Susan Romano, for their time and thoughtful feedback, which helped directly with this capstone. The success of my capstone would not have happened without the continual support of my teacher and advisor from Montana State University, Walt Woolbaugh, who went above and beyond his duties to support me to take a year hiatus during a difficult time. Over the years, he has modeled best practices and has inspired me to be a better teacher. I would also like to thank my Science Reader, Lisa Brown, who gave me valuable feedback throughout the process. Lastly, I'd like to extend a special thanks to Madeline Felts, Assistant Director of the Master of Science in Science Education program at MSU who has been continuously helpful and incredibly responsive.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

ABSTRACT

The goal of this study was to develop an effective method by which to transform cookbook style labs to include varying levels of inquiry. The study focused on the transformation process as well as on the personal impact of modifying curriculum. A peer-reviewed Inquiry Analysis checklist served as a template for incorporating core aspects of Science and Engineering Practices. Afterwards, three teachers used the checklist for each modified lab to determine the level of inquiry. Students were surveyed to determine their perceptions of learning through inquiry. The results showed that the checklist is an evidence-based aid for teachers to use when seeking to analyze an activity and is a useful guide to increase levels of inquiry. It is applicable to any topic and the process of modification is easily repeatable. Student preferences were mixed, showing most prefer some structure and guidance in labs (guided inquiry), while only a small number prefer cookbook style activities. All surveyed students prefer a science class with hands-on activities.

INTRODUCTION AND BACKGROUND

Context of the Study

The science department at Keene High School, in Keene, NH, has been gradually modifying curriculum to align with Next Generation Science Standards (NGSS) since the state adopted the standards in 2016. As a secondary education major in college, I wasn’t exposed to the concept of inquiry-based lessons until my senior year. I remember being intrigued and disappointed that I didn’t receive more adequate training in this pedagogical technique. It wasn't until taking graduate classes through Montana State University that I started learning how to implement inquiry in the classroom and began to appreciate the higher-level thinking required by this student-centered approach. I wanted to make modifying curriculum a priority, so I chose to make it the focus of my Capstone research. My project centered around the process I followed in order to meet this goal. I used a personal narrative explaining how I modified three different labs using resources from peer-reviewed literature for reference. At the core of my values as an eighth-year teacher is a continued passion for my subject area in Earth and Space Science and the desire to motivate students to love science. When students are actively engaged and happy, I get more satisfaction out of teaching and I believe they get more satisfaction out of learning. I have observed a significant increase in engagement when they are doing hands-on labs as opposed to packets of worksheets, for example. While teaching through lectures and packets is less noisy and messy, I’ve found it entirely worth the extra effort and energy to do as many lab activities as possible. One reason for this is because inquiry requires a higher level of thinking compared to recipe-like labs. Practicing this type of critical thinking serves our students well as they can apply this skill to any subject matter. This led to the question of how to modify outdated curriculum to include more inquiry in labs. This Capstone is a Mixed-Methods Design, which gave me the flexibility to collect both quantitative and qualitative data to answer these questions. My intention is to focus mainly on the process I used to shift curriculum.

Focus Question

My focus question for this study was, How can I adjust my pedagogical approach in order to increase student opportunities for learning through inquiry-based investigations?

My sub-questions included the following:

1. What are my colleagues' opinions of these modified labs?
2. What are the student perceptions of learning through inquiry and using science and engineering practices in my classroom?
3. How has modifying curriculum affected me as a teacher?

CONCEPTUAL FRAMEWORK

The role and responsibilities of science teachers continue to be shaped by the current thinking surrounding best practices for constructing knowledge. Just like scientists, teachers have a critical role in upholding society- helping our nation reach the pinnacle of our collective potential. Furthermore, just as scientists construct new knowledge based on evidence, educational practices continue to shift as we improve our understanding of how the brain learns best. Ultimately, we want to help our students develop the skills they need to be independent and competitive in the modern world. The research based NGSS framework seeks to guide educators and school districts in this direction. As states adopt NGSS, it's necessary to devote time to modify curriculum. The country has changed dramatically since the first schools opened in Massachusetts and educational practices need to remain relevant. In order to better understand the background behind how inquiry-based investigations arose as a necessary component of teaching, it's helpful to look at a historical perspective.

John Dewey is credited with being the father of progressive education, which calls for a more student-centered approach, born from his critical view of educational practices at the time. Progressive education focuses on nurturing a student's full potential and "actively promoting and participating in a democratic society" (The American Board, 2017, para. 9). Dewey observed that educational practices at the time relied too much on the memorization of facts and that students weren't actively involved enough. He recommended students be allowed to take more ownership of their learning- to be given the opportunity to ask questions and have hands-on experiences wherein they could investigate natural phenomena. He insisted that this would encourage inquisitiveness and motivate learning (Barrow, 2006). Dewey believed that students should be nurtured to construct their own meaning and that classrooms should be "a social entity for children to learn and problem-solve together as a community" (Williams, 2017, p. 93). Dewey is credited with bringing forth the reform to education that led to the first inquiry-based teaching methods in The United States. Concurrently, there were other historical forces as well that paved the way for policies calling for major educational reform. For example, when the Russians successfully launched Sputnik in 1957 it provoked fears that America was falling behind other countries in technological and military advances. This led to movements in the sixties to train students to be better problem-solvers (Concept to Classroom, n.d.).

National Science Education Standards (NSES) consider inquiry "as the overarching goal of scientific literacy" (Barrow, 2006, p. 268). The NSES and, later on, the National Research Council (NRC) outlined a detailed description of inquiry- what it means for students (the skills and understandings they should walk away with) and the necessary teaching strategies educators need to adopt. In 2012, the NRC published *A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas*, which brought about the union of content (what students learn) and process (how students learn) in educational practices. The Next Generation Science Standards (NGSS), born from this publication, focuses on both teaching content and developing the skills necessary to acquire new knowledge. Furthermore, the document insists content should be relevant to students lives and based on their interests and experiences (Penuel, Harris, & DeBarger, 2015).

As more states formally adopt NGSS, educators will be compelled to become qualified to teach inquiry-based lessons, which will require training. Besides the fact that most educators didn’t receive an inquiry-based experience in school themselves, the method requires an updated approach to the roles in the classroom for both teachers and students. Teachers are encouraged to take the role of a “guide on the side,” while students take a more proactive stance to their learning, with more decision-making authority. It’s important to point out that teachers can choose from a continuous spectrum of inquiry to suit their students’ needs- from open-ended (with little if any teacher direction), to guided (where the teacher provides the question and some parameters for students). The practice of inquiry models the work real scientists and engineers do in order to solve problems and understand the natural world, which makes the approach refreshingly relevant. For students, it requires higher order thinking and more work on their part. In contrast with traditional learning, where students simply seek the correct answer and outcomes, students instead learn to expect unpredictable results and glimpse the often-puzzling nature of real science investigations. Scientists’ make claims that are based on evidence they collect. They communicate their claims while acknowledging the uncertainty of their results (Martin-Hansen, 2002). It is the hope that by modeling curriculum after the work of scientists, students will become more adept in authentic learning and science literacy.

There is a rich body of literature which supports inquiry-based teaching as a necessary component of modern education. One study took place over a ten-year period in an Introductory Biology lab class (Luckie et al., 2012). The goal of the study was to increase the use of inquiry while simultaneously decreasing content. Their method was to create a sequence of increasing inquiry (from guided to open-ended) while measuring results on content-based exams. They used three approaches- week long cookbook labs, two 7-week long inquiry labs and one 14-week long inquiry lab. The results showed that even while reducing content and increasing inquiry, there were upward gains in content-based exams. The rationale was that multi-week studies mimic the work of scientists, whose studies can require significant periods of time extending over months or even years. Through these experiences, students are able to "gain deeper more meaningful understanding of topics, techniques, and the process of doing science…" (Luckie et al., 2012, p. 334). The general principal of reducing content while increasing depth of learning is a practice I'd like to emulate in my teaching. As my school shifts to a Competency-based grading system (at the same time we're shifting to NGSS) this will fit well with the initiatives of our administration. At my school we've done away with midterm and final examinations. We are being directed to modify traditional tests into summative assessments in the form of Performance Assessments. While modifying labs I can incorporate different opportunities for students to learn the material in various modalities. This scaffolding technique helps them internalize the material better than before.

Even though there is growing support nationwide for inquiry-based teaching practices, there are other important factors to consider, including the attitudes and beliefs about inquiry held by teachers. One study, which involved 200 Hong Kong Chemistry teachers (which also surveyed teachers in the U.S.), looked at why, even with a huge body of knowledge supporting inquiry-based methods, many teachers still aren't practicing it in the classroom. The article states that out of 571 Chemistry teachers surveyed in the United States, 45.5% of them didn't give students the freedom to write experimental procedures (Cheung, 2007). The researchers developed a scale to measure teacher attitudes and beliefs toward using guided inquiry in their high school classrooms. They found that both groups (the users and nonusers of inquiry) did recognize the value in a guided inquiry approach. The difference was that nonusers believed that students didn't enjoy guided inquiry and didn't think it was feasible to teach inquiry in high school Chemistry. The author listed additional challenges teachers face which aid in their lack of desire to teach through inquiry, including large class sizes, lack of time for extended projects, and their own lack of confidence to pull it off in the classroom. The conclusion was that in order to support teachers, professional development should be focused on problem solving the issues related to implementation of guided inquiry, rather than focusing solely on the values of it as an instructional pedagogy. This is an important point that I reflected upon while writing my capstone, since this important issue affected me as a teacher.

Another relevant perspective comes from literature focused on what factors control how students develop conceptual understanding while taking part in inquiry-based activities. While pedagogy is an integral part of answering this, a student's motivational beliefs may matter much more (Patrick & Yoon, 2004). The authors studied four eighth graders in order to figure out how their motivational beliefs related to their thoughtfulness and conceptual understanding while conducting inquiry-based investigations. The authors found that all four students were very much motivated and engaged in the activities but that their conceptual understanding varied. Even though they were engaged in inquiry, that didn't necessarily lead to an increase in conceptual understanding. It's important to look at what's behind their motivation. Is it a sound belief in their ability and intelligence and a desire for more knowledge? What are their reasons for engaging in the tasks? Their conclusions were that students don't want to appear like they lack knowledge or ability. They are very much concerned with how they are perceived by others. Focusing on this social dynamic can take away from their ability to understand the content. The bottom line is that inquiry has a lot of merits, but that doesn't matter if teachers aren't supported or feel too anxious about using it in the classroom. Likewise, student beliefs in their own ability and confidence around their peers greatly impacts their ability to learn.

METHODOLOGY

Demographics

Forty-five high school students from two different comprehensive (college prep) level Earth and Space science courses took part in this study. Comprehensive classes at the ninth-grade level can be challenging to teach for a few reasons- some students are over or under-placed in the class for their ability, students tend to be relatively unmotivated, the classes are the largest (not exceeding twenty-four), and the behavior issues can be overwhelming. The students come from ten surrounding towns besides Keene, so some haven't been placed correctly in a Comprehensive level course and would benefit from additional tutor support to be successful. Often times, finding that support is very difficult as our school has a shortage of support staff. Also, by the time I know the students well enough to voice my concern about their placement in the Comprehensive class, the semester is well under way. It isn't always a matter of simply switching a student's schedule. Sometimes, if I detect a learning disability, testing for special education placement can be necessary. It is hard to make time for meetings with special educators and parents before the semester is finished. On the other end of the spectrum are students who should've been placed in an honors level course and who tend to get bored by the slower, less challenging pace. The freshman year is pivotal and teachers have an important role in figuring out what their needs are. The students within the study came from a broad range of socio-economic backgrounds; Keene High School is a Title 1 school. Twelve percent of the students in the two classes had Individualized Education Plans (IEPs). In one of my classes there was a tutor to support those students.

The other class had a student requiring a paraeducator but the position wasn’t filled until well after half-way through the semester.

Treatment

The purpose of this study was for me to learn how to modify recipe-like labs to include various levels of inquiry and to align my curriculum to NGSS practices. At the core of this work was improving my understanding of the NGSS standards and the three dimensions (disciplinary core ideas, crosscutting concepts and practices). I picked three labs from different units to modify: The Geological Time Lab, The Rainbow Density Lab, and The Heat Transfer Lab. All three had been shared with me by my Earth and Space colleagues and are regularly used each semester. I do not have any idea who is the original author of each lab. I recognized each of the labs as particularly devoid of inquiry and suitable for modification. To help me assess the modified versions, I got feedback from two colleagues in my department, which I used to reflect upon my work and make further adjustments. I also conducted a single student survey to gather information about student perceptions in my classroom and preferences. My Mixed-Methods approach used both quantitative and qualitative data to answer my research questions. I focused mostly on the process I used to make this shift, since I see this work as something that needs to be easily repeated to modernize our curriculum. This project has been approved by the Institutional Review Board (Appendix A).

After I conducted each lab with students, I responded to the following prompts in my journal: “What went well” and “What was challenging?” The journal was also used to record observations of student discourse while they worked in groups. I used that data in the analysis of this study and to make further revisions.

While reading an article within *The Science Teacher* journal, I discovered the Inquiry Analysis Tool (Volkmann, 2003) which I ended up using extensively to modify labs (Appendix B). The Inquiry Analysis Tool guided my conversion of cookbook labs to be more inquiry-based. By inquiry-based, I mean that the labs were tailored to be more student-led and utilized more science and engineering practices and collaboration. The checklist is basically the same as the Science and Engineering Practices (SEP), split into four categories: engaging students in relevant questions; prioritizing using lab equipment to collect evidence; formulating explanations based on evidence; and collaborating to communicate explanations. I included a column to document evidence for each item within the section that the labs met (or not)- this was especially helpful when my colleagues offered their feedback using the checklist. In addition, they also wrote comments directly onto the labs that provided valuable suggestions. I believe the checklist was very beneficial and effectively answered my main research question because it acted as a template for a new pedagogical approach to follow.

In order to measure student attitudes toward my teaching methods, I used a Likert Survey once, approximately eight weeks into the semester (Appendix B). The survey results helped me answer one of my sub-questions, *"What are the student perceptions of using science and engineering practices in my classroom?"* While New Hampshire adopted NGSS in 2016, our district only recently began to offer professional development opportunities and workshop time for teachers to begin the work of modifying curriculum. What I've noticed is that students entering ninth grade are not well versed in using SEPs because their elementary and middle schools haven't yet begun the transition to NGSS. Of the 1400 students who attend KHS, many of them come from ten different rural communities besides Keene, which means they come to the high school with different experiences and science content knowledge. It is well known in our science department that there isn't a strong cohesion between the many schools funneling into the high school. Essentially, each school runs it's science curriculum independently of each other, with little to no communication. Students in my classes were accustomed to recipe-like labs (and some insisted they rarely, if ever, did lab work) and the transition to a more student-centered role was frustrating for some.

To insure for validity and reliability, I gave a copy of each modified lab to my support team (two of my science colleagues) as well as the Inquiry checklist and compared their results with my own. I tallied the results (from the three of us) of each yes/no response for all rows of the checklist and created stacked bar graphs of the results. Their feedback helped illuminate further areas that needed improvement and offered some great ideas. In terms of timing, I did use the new labs in the classroom before my colleagues completed their checklists, which means I didn't make additional changes yet based on that feedback.

Data Collection and Analysis Strategies

Once I converted a lab, I completed the Inquiry checklist by selecting yes or no for each component and added any necessary comments in the evidence column. This tool helped me visualize what level of inquiry I was able to achieve with the modifications. I didn’t necessarily aim for completely open-ended inquiry as I found guided inquiry to be sufficient (especially after reading the student survey results). I intended to maximize the use and variety of science and engineering practices.

I organized my data on electronic files and within manila folders. I kept a digital journal. I used separate folders to contain each modified lab version and the completed Inquiry checklists from my colleagues. I saved all paper copy samples of student work (for all three labs) and all the completed surveys.

The combination of the data collection instruments helped me answer my primary question, as well as the three sub-questions with reliability and validity (Table 1).

Table 1. Data Triangulation Matrix.

Research Questions	Inquiry Analysis Tool	Journal	Student Survey
How can I adjust my pedagogical approach in order to increase student opportunities for learning through inquiry-based investigations?	Gives a format to follow consistently	Make notes about ways to improve labs; reflect on colleagues' comments; reflect on success of the lessons	Student feedback will help inform my teaching to suit their needs and ideas
What are my colleague's opinions of these modified labs?	Measures the extent of using science practices from their perspective	Make notes of future modifications based on feedback	N/A
What are the student perceptions of learning through inquiry and using science and engineering practices in my classroom?	Seeks to make learning more relevant to students	Record observations of student discourse, student engagement in the activity, and student quotes	Student feedback will indicate their preferences
How has modifying curriculum affected me as a teacher?	Data will show adjustments to my curriculum	Personal reflections on my growth and the positive and negative aspects of this adjustment to my teaching	Student feedback will affect my choices

For example, for one of my sub-questions, *"How has modifying curriculum affected me as a teacher?"* the Inquiry Analysis checklist and my journal documented how I've changed my curriculum (in some cases over multiple iterations). My data documented what went well and what needed further improvement. The journal provided personal reflections on my growth as a teacher, as well as the positive and negative aspects of adjusting my teaching style. The use of the checklist and the journal complemented each other well since one helped me direct my growth and the other gave me a platform to reflect on how things turned out and how they can be improved.

The Student Survey was used to find out what students preferred and to get their opinion on how well and how frequently I implemented SEPs in the classroom. I looked for trends in how much inquiry they liked the most. I calculated what percent of students preferred x, y, z, etc. and used this quantitative data to supplement my descriptive data. I used their short answers on the survey to gain a deeper understanding of their perspective and added some of these quotes to the study.

DATA ANALYSIS

Results

Analyzing the resulting data using the Inquiry checklist involved comparing my colleagues' responses with my own (for each of the three labs modified), tallying results of the student survey, reading students' short answer responses and highlighting key points, and reflecting upon my journal entries. Stacked bar graphs were produced from each set of data to examine the results.

The Inquiry checklist was used to answer my main question, *"How can I adjust my pedagogical approach in order to increase student opportunities for learning through inquiry-based investigations?"* There are four main criteria within the body of the checklist: developing questions that guide labs; prioritizing the collection of evidence; writing explanations from evidence; and communicating ideas and results. Each section served as a template to follow in order to change the pedagogical approach. The goal of answering my focus question is to better align my pedagogical approach with NGSS. By doing this, I believe students will become more adept at critical thinking, more proactive and independent, not to mention happier doing science. Since the aspects on the Inquiry checklist align with the SEPs adopted by NGSS, I believe incorporating them will help me achieve this goal.

The first lab I modified, called the Geologic Calendar lesson, had students calculate how many days from the present a list of earth events took place and then label them on the calendar months provided (the lab was renamed Geologic Timeline Lab, Appendix C). After students finished labeling and decorating, there were a few questions to answer that were nearly all recall based. I knew that to improve the lab I needed to center the lesson around a focus question, and make the questions more rigorous and thought provoking, with a Claim-Evidence-Reasoning format. I found a resource online that separates Earth's events into three categories- Life Transformations, Mass Extinctions, and Geologic Events (National Science Foundation, 2001). The main focus question of the new lab became, "What is the connection between Transformations of Life, Mass Extinctions, and Geologic Changes in earth's history?" By placing all the events along their timeline, students were led to the understanding that geologic changes often drive extinctions and that extinctions are a catalyst for life transformations. Students were asked to write a Claim to answer the focus question, use facts from their timeline as supporting Evidence and finally write a response showing Reasoning, explaining how their Evidence supports the Claim.

I introduced the Geologic Timeline Lab by using a lesson I discovered online that had them create a personal timeline based on their life (It's a Matter of Time, n.d.). I hoped it would help them connect with the project on a more personal level. It was a good warm-up for observing the strengths and weaknesses in their measurement skills and they seemed to have fun making it, although it took a lot longer than expected. When I read a few of the completed projects I got to know my students in much more detail. The original lab had them using math and computational thinking to calculate the number of days from the present on their calendar. They used this data to develop a model of earth's history as if it took place within a calendar year. The modified Geologic Timeline lab also has students using the same measurement and calculation skills, but has added other core NGSS components, including Engaging in Argument from Evidence, Constructing Explanations, and Obtaining, Evaluating and Communicating Information. Students were required to pick an additional five events (that interest them) to place on their timeline. This gave them a chance to decide what data to collect. In terms of communicating with their peers, I gave students time to talk about the answers to the questions to help them develop their Claim. I didn't require presentations of the completed timelines but concluded by asking students to explain what surprised them the most about this activity. Afterwards, I completed a journal entry answering two questions: *What went well? What was challenging?* These types of entries helped answer my sub-question, *"How has modifying curriculum affected me as a teacher?"* Below is my journal entry written after modifying the first lab:

What went well?

"Using the checklist definitely was helpful as a guide for the modifications. It was clear that I had done a lot to improve the lab and bring more inquiry into the assignment."

What was challenging?

> It was a lot harder than I thought it would be taking an existing lab and modifying it. It took me several days to juggle different ideas of ways to address the issues with the old lab. I ended up modifying not just the original lab but also two different lessons I found online, which I incorporated into the finished product. There was a lot to consider, just like with the creation of any lesson. I had to think about the students' abilities and I'm concerned this new lab will be too hard for them. There are more math calculations to do and measuring to scale can be tricky for some. This version of the lab will take longer to complete. I'm also nervous they won't be able to see the big picture and answer the focus question. My students are not the most motivated individuals so giving them more challenging

> work feels like a risk. I'm looking forward to journaling during and afterwards as that data will help refine any problematic areas.

My two colleagues provided useful feedback about the Making Sense of Geologic Time Lab. Both of them felt I could improve the focus question using more student-friendly language. As the Inquiry Analysis Checklist Results indicate (Figure 1), students aren't given an opportunity to generate or refine questions for this activity. Even though they are given choice of data to collect as the checklist indicates (by choosing five additional events in earth's history) my colleague doesn't think that choice of data is necessarily relevant to the objective- to identify patterns between life's transformations, mass extinctions and geologic changes. Also, they felt the timeline could get too crowded with additional events added. I found this to be true- after viewing completed timelines, I noticed it was difficult for students to fit everything (especially the many events that occurred close to the present). Another weakness of the lab, which the checklist shows, is that there are recipe-like procedures to follow. However, a strength of the activity is that students are using math and computational thinking (using their senses and instruments to collect evidence) and they are generating explanations based on evidence and reasoning. This would certainly qualify as a guided-inquiry lab, as it is a structured activity. I could further improve the lab by possibly reducing the overall number of events, skipping the pick-your-own section, and by giving students choice to work with a partner (which would save time). Overall, the students didn't love this activity because it ended up being days of measuring, which got tiring. I think the point of the lab was lost to them because they were so focused on calculations, measuring, and fitting so many events on a thin piece of paper. I don't think I'll use this lab in the same way next time due to their feedback about it taking too long. If I could modify it again to be a shorter activity, require group work and have them present the finished product, it would be a stronger activity.

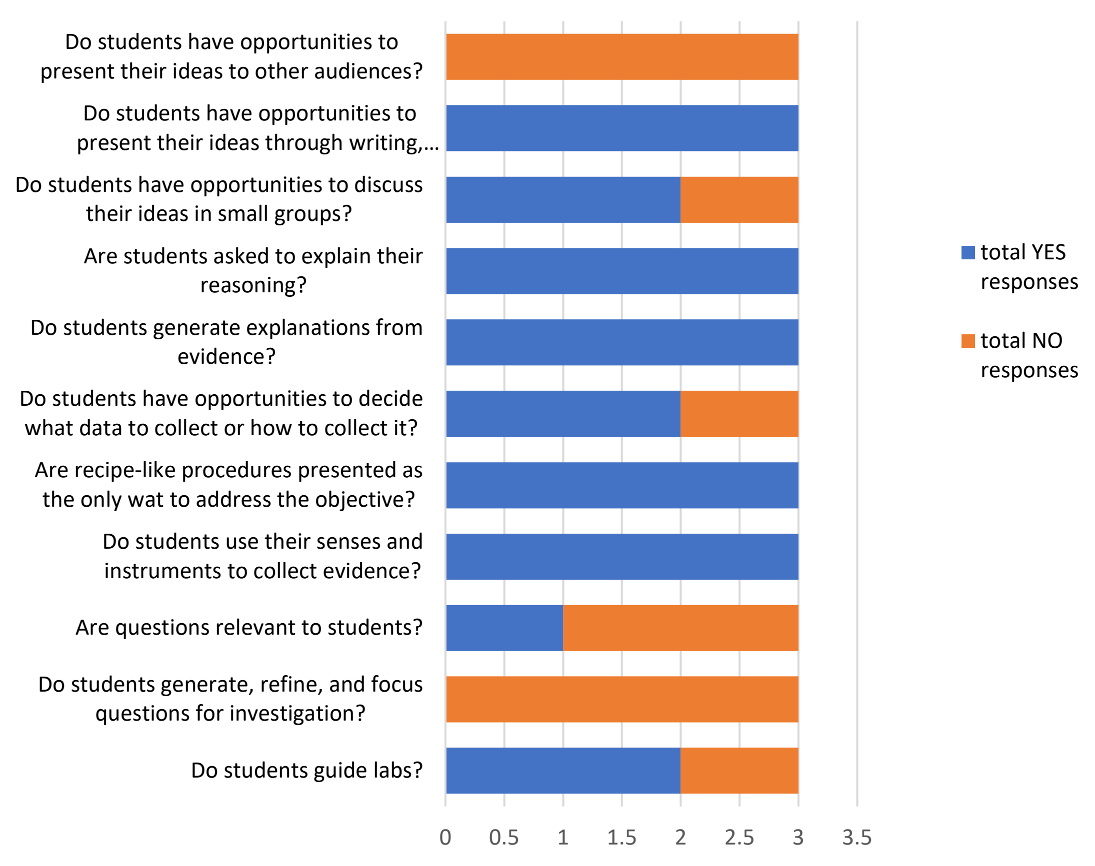


Figure 1. Inquiry analysis checklist results for geologic timeline lab, (*N*=3).

The second lab I modified, called the Rainbow Density Lab (Appendix D), has always been a class favorite. I teach it during a Metric Measurement unit at the beginning of the semester. The purpose of the lab is to mix salty solutions of different colors and successfully stack them in a graduated cylinder in order to make a perfect rainbow- which provides a pleasing example of the principal of density. Originally the lab gave step-by-step procedures: specifying the mass of salt to add to each test tube, which food coloring dye to add, and an order to follow when pipetting solutions from the test tubes to the graduated cylinder. There were no mathematical calculations required and the only analysis involved coloring a diagram of a graduated cylinder to show results. Using the Inquiry checklist as a template for ideas, I had students read an article about the Dead Sea before the lab and showed them short phenomena-based video clips and images about the area to pique their interest. The clips showed what the salt crystals look like that wash up on shore, a person trying to swim there, an image of a cross section showing its position relative to sea level and a map showing the tectonic rifting of the region. While I kept the methods detailing the basic steps to take, I modified them by allowing students to choose how much salt to add to each test tube, the food dye color for each test tube, as well as to decide which order to add them to the cylinder. This resulted in failure to create a perfect rainbow for multiple groups, but they were instructed to add half their solution on the first try and were encouraged to consider what they could do differently to get it to work on a second try. Most groups had time to get it right, which was pleasing to see. The next part of the lab I modified was adding a section to calculate the density of each salty solution. They had already learned the density equation and the density of water in previous classes and I hoped they would remember or use their notes for reference. Since I told them to add 20 mL of water to each test tube as a starting volume in which to dissolve the salt, they were able to calculate the density for each solution (assuming the drop of food dye is negligible). For their conclusion, I added a Claim-Evidence-Reasoning section for them to respond to the question, “How does a change in mass (an increase/ a decrease) affect density if volume stays constant?” Reflecting on these modifications using the Inquiry checklist, the lab has been improved by adding choice in the procedures, mathematical calculations, and asking for explanations from evidence from their data. Here are some of my journal entries reflecting on the use of this lab:

What went well?

> I saw a lot of lightbulb moments today when some groups realized their solutions had all mixed together due to adding the least dense solutions to the cylinder before the densest solutions. This allowed them to figure it out for themselves. The math section was challenging for a lot of them and most groups needed me to remind them to use the density equation with water's density filled in as 1 g/mL, the volume of each test tube as 20 mL, so they could figure out the mass of each salty solution (20 grams plus the grams of salt). The discourse in the groups was interesting because they were clearly working on the problem together, rather than just plugging and chugging away. Reading their responses in the Evidence section was satisfying because they used their density calculations to explain why an increase in mass makes something denser.

What was challenging?

"Some groups added way too much salt in the test tubes, which didn't end up dissolving well, so I need to give them a range of salt (0-5 grams would work) so they're not oversaturating the solution."

I'm convinced that guided inquiry was the best approach, in this case, and helped students be successful, while also challenging them more than the original. My colleagues agreed that some directions were necessary. One suggestion I'll consider is adding time before the lab for students to experiment with salt densities so they can determine what range of salt to add. That way, they can determine for themselves that a mass over five grams will be impossible to dissolve adequately. One colleague thought that, although the questions in the lab are scientifically oriented, I can improve them further and make them more compelling to hook students. The Inquiry checklist results from me and my colleagues show we were largely in agreement about most components of Inquiry, except on students having the opportunity to discuss ideas in small groups and making questions relevant to students (Figure 2). I attempted to make the questions relevant by showing clips of the Dead Sea, hoping to inspire their curiosity to visit one day, but I may need to brainstorm some additional ways to make it relevant to them. An additional note is that I didn't tell my colleagues about the article and clips I used in the introduction. I should have, since it may have changed the results of the checklist.

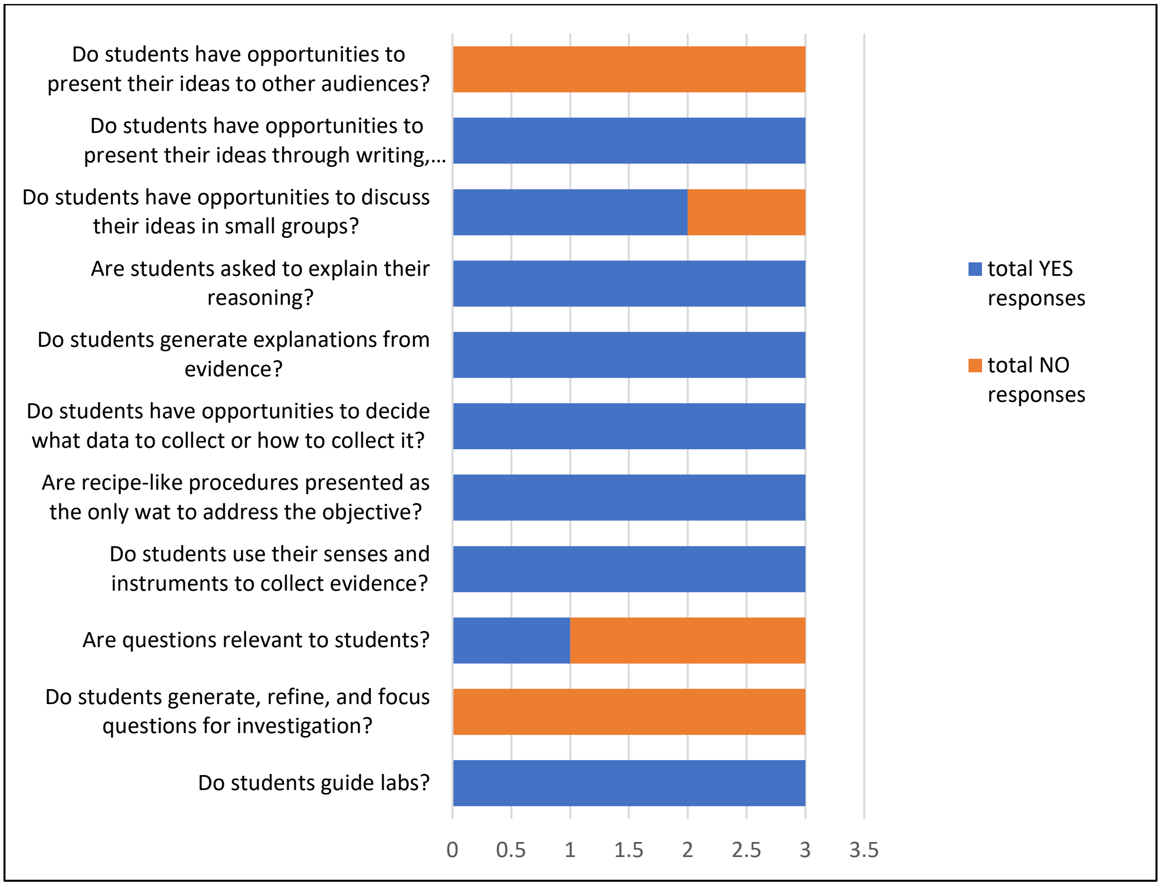


Figure 2. Inquiry analysis checklist results for rainbow density lab, (*N*=3).

The third lab that I modified for the purposes of this Action Research is the Heat Transfer Lab (Appendix E). This is included toward the beginning of a Meteorology unit after students have learned about three mechanisms of heat transfer. The purpose of the lab is for students to learn about the mechanisms of conduction, convection and radiation by using a calorimeter to transfer heat from a hot cup to a cold cup using an aluminum bar. Originally, the ready-made calorimeter was provided to students and I would show them how to assemble it with thermometers. The directions contained detailed procedures to follow- how much water to add to each cup, how long and how many intervals to take the temperature, followed by directions to make a double line graph, followed by some conclusion questions. Using the Inquiry checklist and a lab I discovered online called, “Engineering a Calorimeter: Designing and Testing a First Prototype” (Hill, n.d.), I added an introductory letter from a fictitious company to give students as an introduction. The letter, written by a character named Mr. Cal R. Imeter, asks for their help in developing a prototype that allows heat transfer between two cups, can hold liquids, but keeps all the heat inside the container. The design constraints said the device needed to transfer heat from two very different temperature liquids through a metal bar that connects the two cups. I listed the materials they could choose from, which included different types of disposable cups, a hot plate, thermometers, tape, plastic and bubble wrap, aluminum foil, to name a few. They were also told to modify the cups in any way they like and to measure the temperature of the liquids without having to take anything apart to do so. The questions that followed helped provide a place in which to discuss ideas with their partners, review the restrictions and functional purpose, a place to draw the design, decide what data to collect and explain the procedures they would use to gather data. The conclusion used a Claim-Evidence-Reasoning format to have students explain what design is best for the challenge, what evidence from their data supports the claim, and reasoning about how their evidence supports the claim and what they could've done to improve the design.

The modified version of the lab is guided inquiry- it allows students more autonomy by building their own calorimeter, deciding how to collect their data, writing their own procedures and using evidence to form explanations. My colleagues and I were mostly in agreement on the Inquiry checklist (Figure 3). A colleague wrote that the question the lab poses is relevant to students because it follows a business model from the real world. Once again, I could improve it in the future by having students generate and refine focus questions for the lab, although they have to come up with a solution to the problem themselves. Another weakness of the modified version is that it doesn't offer an opportunity for students to present their ideas to other audiences. One colleague recommended I require presentations using white boards for groups to write up their lab.

I wrote the following journal reflections after students completed the work:

What went well?

> Watching and listening to the groups work, I was struck by the fact that there is more than one correct way to collect data. Different groups took the temperature at varying intervals and for different periods of time, but their results were still accurate. Groups worked hard to perfect their designs, since they were given freedom how to build them; some groups even built more than one and chose the better design to proceed with. It was nice to see their ideas running the show. With the original lab they just followed directions with no input.

What was challenging?

> The flip side of having them choose how to take the data is that I wasn't sure if some groups collected enough to make accurate graphs. One group took the temperature every five minutes for a total of twenty minutes, so they made a double line graph with only four data points for each cup. Some of them are still making graphs using inconsistent scales which, when combined with only having four data points, makes a skewed graph that will need to be redone.

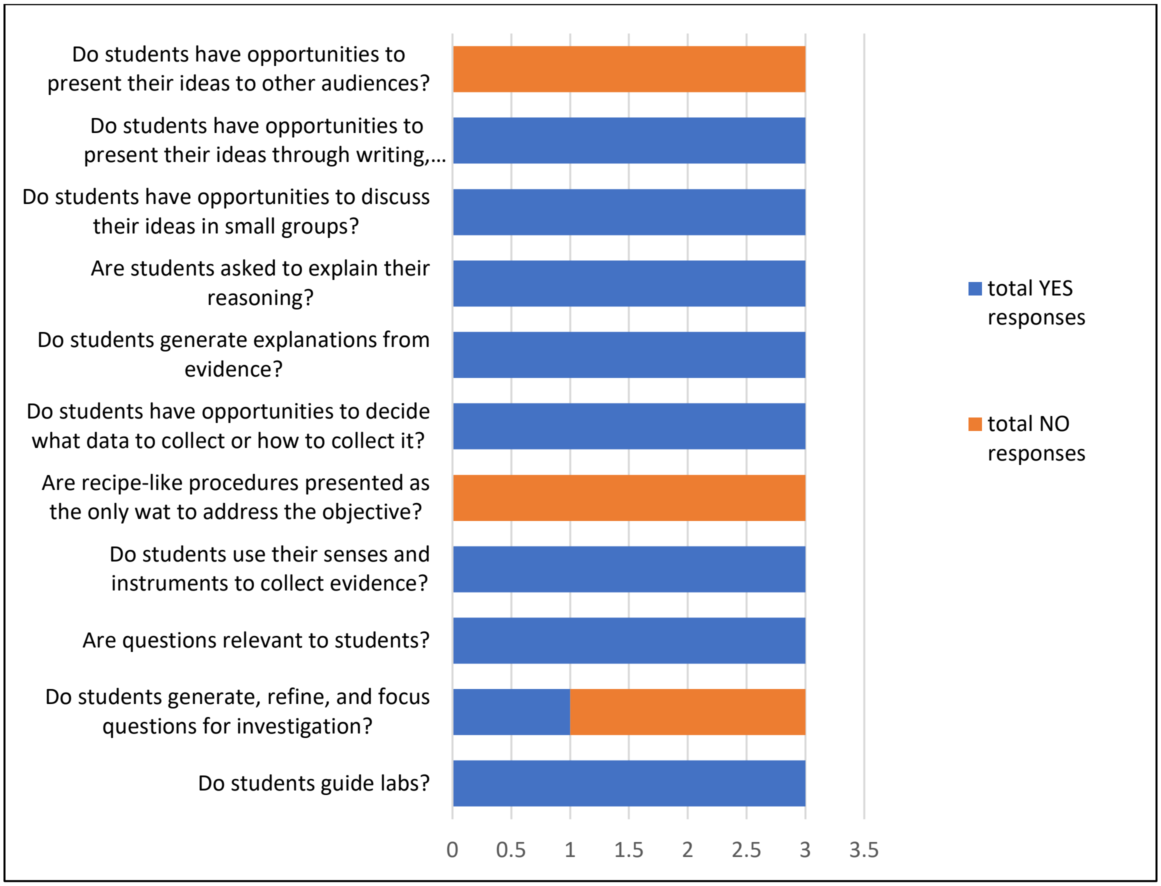


Figure 3. Inquiry analysis checklist results for heat transfer lab, (*N*=3).

I conducted a Likert Student Survey one time about two months into the semester to get student feedback about the level of inquiry they preferred and their cognizance of what scientific practices they were utilizing in my class (Appendix F). I used the results as a way to determine steps moving forward. For each question on the survey, students selected from a choice of five possible answers: *strongly agree, agree, neutral, disagree,* *and strongly agree* (Figure 4). There were some short answer sections intermixed as well. There were forty-three students who chose to take part in the survey (a few elected to skip it). Ninety-three percent of students surveyed indicated they strongly agree or agree that they prefer science classes with hands-on activities and labs. I wasn't surprised by these findings, as it was apparent how engaged and more lively students were when they got up from their desks and got busy doing something hands-on. In terms of whether they felt the material we covered in class was relevant to their lives, 14% said they strongly agree, while 47% were neutral. This is an area that I recognize needs to be improved. It connects back with my colleagues' comments on all three labs that the focus questions could be written to be better 'hooks' and more interesting for students. Thirty-seven percent of students said they prefer recipe-like labs to follow, while 53% were neutral. This wasn't very surprising as students often express how confusing it is to have to figure things out for themselves. One student elaborated to say, "I like having reassurance that I'm doing it right." Another said, "Because having some creativity and freedom is good, but not to the point that I don't know where to start." However, 9% of students disagree or strongly disagree with this statement. One wrote, "It's fun to figure things out." Another said, "You can decide what you want to learn." The statement that supported inquiry the most was, "I learn the material more when I have to figure it out." Forty-seven percent of students surveyed they prefer open-ended labs where they have more freedom and get to decide how to run the experiment. What this indicates is that students prefer guided inquiry, with some structure provided by the teacher. This shows that by modifying labs using the Inquiry checklist, I can find a balance that serves the majority of students and that includes more SEPs involving critical thinking, evidence-based reasoning and choice.

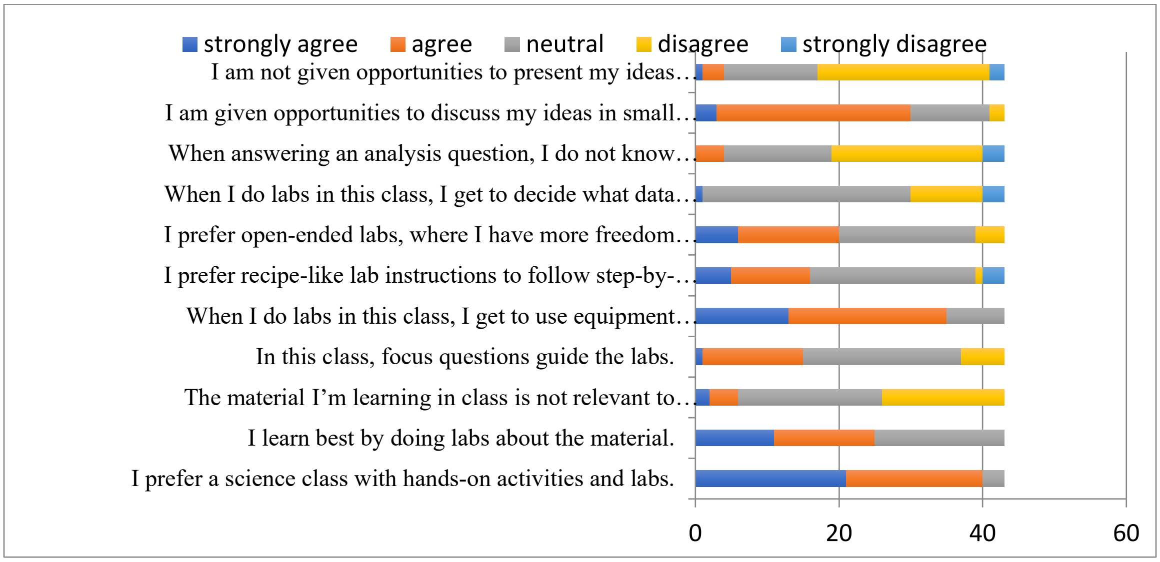


Figure 4. Individual responses to student survey, (*N*=43).

There are both benefits and new challenges to identify when reflecting upon how this approach has affected me as a teacher. Modifying curriculum and adding more inquiry has made teaching more enjoyable because I like challenging students cognitively and making them more active participants in their learning. All of us get more out of the lessons in this manner. It is rewarding to watch them work together to solve problems in the same way one feels a sense of accomplishment solving a puzzle with someone. I'm convinced that continuing to modify labs using the Inquiry checklist is one of the best things I can do to improve my effectiveness as a teacher. A challenge will always be making time for this process, but that can be overcome with hard work and patience. However, a challenge is that there are certain classes that I resist doing guided inquiry with because of the lack of seriousness and behavioral challenges. The easiest group to challenge is the honors level because they stay focused and care about their grades. The foundations level classes have more behavioral issues but also the most learning disabilities as well. I’m always cautious of challenging their abilities too much, causing them to quit or act out. It’s very important to recognize and support students’ emotional well-being as it is a critical component of learning. In foundations classes, I often struggle to have adequate adult support, which is a district wide issue, due to lack of staffing. In all of my classes student beliefs in their own ability and confidence around their peers greatly impacts their ability to learn. Ninth graders can be very self-conscious, and I need to be aware of how this can impact their willingness and decision making. Group work that requires a lot more discourse and proactive thinking could potentially trigger social anxiety amongst peers beyond what they already feel.

CLAIM, EVIDENCE, AND REASONING

Claims for the Study

The goal of this Action Research was to answer the focus question, *"How can I adjust my pedagogical approach in order to increase student opportunities for learning through inquiry-based investigations?"* My claim was that by using a simple and reliable Inquiry checklist that followed NGSS' Science and Engineering Practices (SEPs), I could effectively add more inquiry into labs. The same checklist is a valuable tool for teachers to reflect upon each other's curriculum and the extent to which an activity incorporates SEPs.

The evidence I collected to support my claim centered around the process I used to improve labs, rather than a direct comparison between the old version and the new. The reason for this has to do with practicality. This study was intended to help me rethink and renew old material quickly and efficiently. This is an ongoing process that will need to be repeated countless times over years within the time constraints of the teaching profession. That being said, the combined data of the Inquiry checklists completed by me and my colleagues, the student survey results, and my journal entries show not only how I can adjust my curriculum but also reveal the answers to my sub-questions.

My colleagues' responses to the labs were positive and show that I have indeed incorporated multiple SEPs within each. Since there were some missing components of the SEPs in each lab, none of them would be considered open-inquiry, but rather guided-inquiry. My student survey indicated this is what the majority of my freshman prefer, so I'm satisfied with the results.

I was happy that most of my students participated in the survey and seemed to take it seriously. I am pleased that most students seem to enjoy the activities. For me, I'll never think about another lab the same way again. I'd like to continue this work, slowly but surely, to make my teaching more meaningful for students. I do believe other teachers can benefit from the Inquiry checklist as a template for modifying labs. Continuing this work, together, will meet the demand from our administration and the state to align curriculum with NGSS.

Value of the Study and Consideration for Future Research

I've used the Inquiry Analysis checklist for three labs successfully and I believe it has value that extends beyond my capstone project. I've learned more about what inquiry is and how to implement it in my classroom; I feel better prepared to include these practices in the future. Aligning curriculum to NGSS is one of my school district's goals that teachers are mandated to meet. The knowledge I've gained through this study could strengthen my department because I can share this technique with other teachers. In the future, I'd like to present the Inquiry checklist to my colleagues and explain how I used it, so they can benefit as well. The sooner elementary and middle schools begin to adopt NGSS, the easier it will be for science teachers at the high school to teach through inquiry.

One thing I'd like to investigate further is how to connect my labs more effectively to students' lives. The data showed that this was an area of weakness in my labs. I'd like to work on developing better questions and to give students more experience pursing their own questions.

Impact of the Action Research on the Author

This study has inspired me to continue to help students gain more independence and control of their learning. I'm looking forward to modifying more labs but also to shift other aspects of my teaching. For example, I'm realizing that notes can sometimes be student-directed (self-guided) versus teacher directed and students will get the same background material. I've also realized that by building short formative assessments (especially that require student-student discourse) into daily lessons, it helps scaffold material and improves cognition. Further, grading labs to give immediate feedback is necessary so students can fix their own misconceptions quickly.

From experience, I already knew that students love hands-on activities. Their lives revolve around their social nature and labs allow them to interact. Through this study I've realized that guided inquiry is a powerful tool to get them to talk about the content and to conceptualize ideas to complete the lab. It turns the student discourse into something more productive (rather than the off-topic conversations that occur). By grouping students together who have different strengths, I have seen them work in groups more effectively.

REFERENCES CITED

Angelo, T. A. (2016). *Classroom assessment techniques*. John Wiley & Sons.

Barrow, L. H. (2006). A brief history of inquiry: From Dewey to standards. *Journal of Science Teacher Education,17*(3), 265-278. http://doi:10.1007/s10972-006-9008-5

Casper, K. (2015). *Increasing student achievement in science through the use of the 5 E instructional method.* (Unpublished Professional Paper). Montana State University, Bozeman, Montana.

Cheung, D. (2011). Teacher beliefs about implementing guided-inquiry laboratory experiments for secondary school chemistry. *Journal of Chemical Education*, 88(11), 1462-1468.

11 Facts About the History of Education in America. (2017, January 18). https://www.americanboard.org/blog/11-facts-about-the-history-of-education-in-america/

Hill, E. (n.d.). *Engineering a Calorimeter: Designing and Testing a First Prototype*. Emilie Hill. https://betterlesson.com/lesson/639154/day-2-of-4-engineering-a-calorimeter-designing-and-testing-a-first-prototype?from=breadcrumb_lesson

It's a Matter of Time. (n.d.). https://www.nps.gov/pefo/learn/education/classrooms/upload/paleo_lesson3.pdf

Llewellyn, D. (2004). *Rubric for becoming an inquiry-based teacher.* http://www.pkwy.k12.mo.us/intra/professional/tip2_resources/RubricInquiryTeacher.pdf

Llewellyn, D. (2015). *Teaching high school science through inquiry and argumentation*. Thousand Oaks: Corwin.

Luckie, D., Aubry, J., Marengo, B., Rivkin, A., Foos, L., & Maleszewski, J. (2012). Less teaching, more learning: 10-yr study supports increasing student learning through less coverage and more inquiry. *Advances in Physiology Education, 36*(4), 325-335.

Martin-Hansen, L. (2002). Defining inquiry: Exploring the many types of inquiry in the science classroom. *The Science Teacher., 69*(2), 34-37.

National Science Foundation. (2001). *Deep Time and the History of Life.* https://www.pbslearningmedia.org/resource/tdc02.sci.life.div.lp_divdeeptime/deep-time-and-the-history-of-life/

(n.d.). https://www.thirteen.org/edonline/concept2class/inquiry/index_sub4.html

Patrick, H., & Yoon, C. (2004). Early adolescents' motivation during science investigation. *Journal of Educational Research, 97*(6), 319-328.

Penuel, W. R., Harris, C. J., & Debarger, A. H. (2015). Implementing the Next Generation Science Standards. *Phi Delta Kappan, 96*(6), 45-49. http://doi:10.1177/0031721715575299

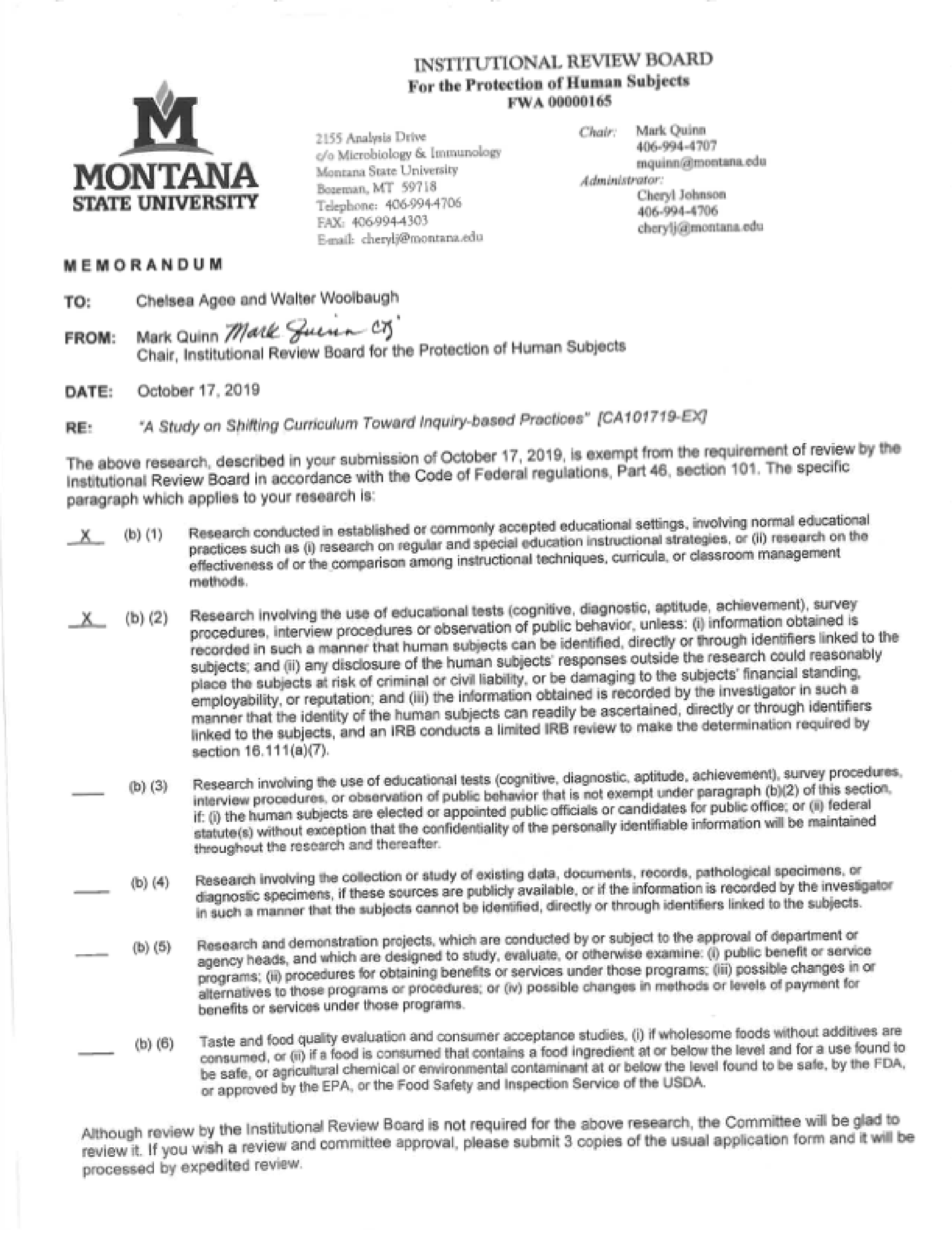
Williams, M. K. (2017). John Dewey in the 21st Century. *Journal of Inquiry and Action in Education, 9*(1), 91-102.

Volkmann, M. J. (2003). Rethinking laboratories. *The Science Teacher, 70*(6), 38-41.

APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD EXEMPTION



INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

MONTANA STATE UNIVERSITY

2155 Analysis Drive
c/o Microbiology & Immunology
Montana State University
Bozeman, MT 59718
Telephone: 406-994-4706
FAX: 406-994-4303
E-mail: cherylj@montana.edu

Chair: Mark Quinn
406-994-4707
mquinn@montana.edu
Administrator:
Cheryl Johnson
406-994-4706
cherylj@montana.edu

MEMORANDUM

TO: Chelsea Agee and Walter Woolbaugh

FROM: Mark Quinn Mark Quinn CJ
Chair, Institutional Review Board for the Protection of Human Subjects

DATE: October 17, 2019

RE: *"A Study on Shifting Curriculum Toward Inquiry-based Practices" [CA101719-EX]*

The above research, described in your submission of October 17, 2019, 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; and (iii) the information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by section 16.111(a)(7).

___ (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

INQUIRY ANALYSIS TOOL

Does the material…	Yes	No	Evidence and Comments
1. Engage learners in scientifically oriented questions?			
◊ Do questions guide labs?			
◊ Do students generate, refine, and focus questions for investigation?			
◊ Are questions relevant to students?			
2. Ask learners to give priority to evidence?			
◊ Do students use their senses and instruments to collect evidence?			
◊ Are recipe-like procedures presented as the only way to address the objective?			
◊ Do students have opportunities to decide what data to collect or how to collect it?			
3. Encourage learners to formulate explanations from evidence?			
◊ Do students generate explanations from evidence?			
◊ Are students asked to explain their reasoning?			
4. Expect learners to communicate and justify their proposed explanations?			
◊ Do students have opportunities to discuss their ideas in small groups?			
◊ Do students have opportunities to present their ideas through writing, drawing, or thinking?			
◊ Do students have opportunities to present their ideas to other audiences?			

APPENDIX C

GEOLOGIC TIMELINE LAB

Geologic Timeline Lab

Question: What is the connection between Transformations of Life, Mass Extinctions, and Geologic Changes in earth's history?

Earth's history is marked by a series of transformations, mass extinctions, and geologic changes that have taken place over the course of 4.6 billion years. How does that compare to the amount of time humans have been around? One of the many reasons evolution is a difficult topic to grasp is that it takes place in very small steps often over a long period of time. Understanding geologic time, what scientists sometimes call "deep time," will help you better understand the fossil evidence for evolution. In this lesson, you'll learn about deep time by putting certain events of earth's history on a timeline the distance between your fingertips (your wingspan). Think of the example we did in class making a personal timeline of your life based on your 'wingspan'. Your challenge is to use the length of your wingspan and place events of earth's history on it geologic time scale. Figure out what you will use (distance, time, other?) then calculate how many millions of years will equal each unit in your scale, record on your data table. Your scale needs to include the events listed below. Mya stands for millions of years ago.

Learning Targets:

- I can determine relative lengths and orders of the major eras in Earth history.
- I can differentiate relative and absolute orders of major life events as recorded in the fossil record.
- I can create an accurate scale of Earth history that reinterprets the enormity of it into a manageable, relatable perspective.

Steps:

1. Write down your arm span below in cm (round to the nearest whole number).

__________cm

2. Use ratios to create a scaled timeline of earth's history to fit between your two outstretched arms. Use the equation for each of earth's events and write the distance away from the present on the column provided.

$$\frac{\text{4600 my}}{\text{your arm span (cm)}} = \frac{\text{the event age (mya)}}{x \text{ (distance from the present on your timeline, cm)}}$$

Ex: If your arm span is *176 cm* and you are trying to figure out where to put the dinosaur extinction event *(65 mya)* on your timeline *(x, the unknown)*:

$$\frac{\text{4600 my (age of earth)}}{\text{176 cm}} = \frac{\text{65 mya}}{x \text{ (distance from the present on your timeline, cm)}}$$

Using cross multiplication, we get the following equation:

$$\boxed{x = \text{your arm span (the event age in mya) / age of earth}}$$

Ex:

$$x = 176\ (65) / 4600$$

Location on your timeline = 2.5 cm away from the present day end of your timeline

3. Use a meter stick and place all the earth events along your timeline using a mark and labeling the name of the event directly on the timeline. **Note: some of the events occurred less than a millimeter from the present. You'll have to draw those in right up close to the present. If 2 or more events occurred very close together, just draw them side by side.*

4. Once your timeline is complete, answer the analysis questions that follow. Pass in your timeline and this packet.

Transformations of Life on Earth	Millions of years ago	Distance from the present day (cm) your arm span (the event age in mya) / age of earth
First evidence of life	3,850	
Oldest fossils	3,500	
First evidence of soft-bodied animals	900	
The Cambrian Explosion of Life	530	
First land plants and fish	480	
First reptiles	350	
First mammals and dinosaurs	220	
First birds	150	
First hominids	5.2	
Modern humans	0.1	
Oxygen Revolution	2500	

Mass Extinctions	Millions of years ago	Distance away from the present day (cm) your arm span (the event age in mya) / age of earth
Some single-celled animals and soft-bodied animals *Vendian Extinction*	543	

Reef-builders and other shallow-water organisms *Cambrian Extinction*	520	
Twenty-five percent of marine invertebrate families *End Ordovician Extinction*	443	
Fifty to fifty-five percent of marine invertebrate genera *Late Devonian Extinction*	364	
Ninety percent of all species *End Permian Extinction*	250	
About 50 percent of marine invertebrate genera *Late Triassic Extinction*	206	
Dinosaurs and 60 to 80 percent of all species *End Cretaceous Extinction*	65	
Foraminifera, gastropods, and sea urchins *Late Eocene Extinction*	33	
Many woodland, plant-eating herbivores *Miocene Extinction*	9	
Nearly all mammals and birds over 45 lbs. Late *Pleistocene Extinction*	0.1	

Geologic Changes	Millions of years ago	Distance away from the present day (cm) your arm span (the event age in mya) / age of earth
Formation of the great oceans	4,200	
Continents begin shifting	3,100	
Rodinia supercontinent breaks apart	700	

Gondwana forms	500	
Great mountain ranges form	425	
Formation of Pangaea supercontinent	200	
Pangaea supercontinent breaks up	200	
Inland seas dry up	20	
Global ice ages begin	2	

Era	Millions of years ago	Distance away from the present day (cm) your arm span (the event age in mya) / age of earth
Beginning of the Precambrian Era	4600	
Beginning of the Cenozoic Era	66	
Beginning of the Mesozoic Era	248	
Beginning of the Paleozoic Era	543	

Pick 5 additional interesting geologic events to share on your timeline and research the age of each in millions of years ago (mya).

Event	Millions of years ago	Distance away from the present day (cm) your arm span (the event age in mya) / age of earth
1.		
2.		
3.		

4.		
5.		

Analysis Questions:

1. How old do scientists think Earth is in millions of years? How many billions of years is that?

2. Of the four eras (Precambrian, Paleozoic, Mesozoic, and Cenozoic) which one represents the longest amount of time?

3. What is the most recent geologic event(s) that we plotted?

4. How has the complexity of life changed over time?

5. When did oxygen become part of Earth's atmosphere?

6. State a Claim to answer the question: What is the connection between Transformations of Life, Mass Extinctions, and Geologic Changes in earth's history?

7. What is your Evidence? Use your timeline and give specific examples to back up your Claim.

8. Explain your Reasoning. How does the Evidence you listed support your Claim?

9. What has surprised you most about this activity?

APPENDIX D

RAINBOW DENSITY LAB

RAINBOW DENSITY LAB

The purpose of this lab is to create salty solutions of different densities in order to demonstrate the principle of density. Your task is to create a perfect rainbow in a graduated cylinder by determining how much salt to add to each test tube. *You get 2 tries to get it right.*

1. If solutions of different densities are layered, which one will be on the top and bottom?

____

2. Hypothetically, what's a way to control the density of a substance <u>without changing</u> what's in it?

____

3. Consider the Dead Sea in the Middle East. How did the water get so dense? How does this affect swimmers? *Include information from the article we read in class.*

____
____
____

MATERIALS:

Food coloring	water	glass stirring rod
kosher salt	balance	test tube rack
5 test tubes & a beaker	pipette	graduated cylinder (50 ml)

METHODS:

1. Decide with your partner how much salt to add to the test tubes below and record on the data table. Use between 0-5 grams in each, but each needs to be different. Add the salt into each test tube.
2. Fill the beaker with HOT water, then transfer 20 mL into each test tube.
3. Dissolve the salt using the glass stirring rod. Be patient, this will take some time.
4. Decide what color each solution will be and record on the data table.
5. Add just one drop of food coloring to each tube and stir until it is mixed.
6. Using a pipette, carefully transfer 10 ml of the solution from test tube #1 to the graduated cylinder. <u>Add each layer carefully by running the solution slowly down the side of the TILTED cylinder.</u>
7. Continue adding 10 ml of each solution in the order that you and your partner decide upon.

DATA:

Test tube #	Grams of salt	ml of water	color
1	____	20	_____________
2	____	20	_____________
3	____	20	_____________
4	____	20	_____________
5	____	20	_____________

OBSERVATIONS:

4. Calculate the density of each saltwater solution in g/mL (assuming the drop of food coloring is negligible). ******You will have to include the mass of 20 mL of water in order to get the right answer.* *SHOW YOUR WORK in the space below- include all calculations below, not just your answer. Include units.

Test tube #	1	2	3	4	5
Density:					

ANALYSIS:

5. Either make a colored sketch of the layered solutions in a graduated cylinder or label the colors in a graduated cylinder (use the space to the right)

6. Which color settled on the bottom? Which color sat on top? Why?

____

7. Were you able to create a perfect rainbow? Why or why not?

____

CONCLUSIONS:

8. How does a change in mass (an increase/ a decrease) affect density if volume stays constant?

CLAIM:____

____

EVIDENCE:____

____

REASONING:____

____

APPENDIX E

HEAT TRANSFER LAB

Closed System Enterprises

Dear Earth and Space Science Students,

I understand you are studying heat transfer and I need your help! I am looking for the best design in creating a device that allows heat transfer between two cups and can hold liquids, but does not transfer heat to the surroundings outside the container. Your design needs to transfer heat from two very different temperature liquids (one in each cup) through a metal bar that connects the two cups.

I need to mass produce these devices at a minimal cost; therefore, I am sending you both paper and styrofoam cups (since my warehouse is full of them) to use in your design. Please limit your design to include no more than 2 cups, in any combination you like. You can modify the cups any way you see fit, but please don't damage the thermometers I'll provide. I will also make available some additional materials for you to utilize.

Remember- I want the heat loss to the outside of the container to be as close to zero as possible. And another thing, I need to be able to measure the temperature of substances inside the containers without having to take them apart to do so!

Please submit your prototype and surrounding data explaining why I should choose to manufacture your design. I am looking forward to your creative solutions to this perplexing problem.

Sincerely,

Cal R. Imeter

Heat Transfer Lab

Materials:

hot plate, 1 glass beaker, 2 thermometers, 1 aluminum bar, 2 cups (you choose either paper or styrofoam), other additional materials (aluminum foil, plastic wrap, bubble wrap, tape, other?), scissors, paper to make a data table.

*tips: decide what *constants* are necessary, take plenty of data to make a graph over time, keep thermometers inside the liquid the whole time.

Before designing the prototype: answer the following questions for planning purposes:

1. Based on the request from Mr. Imeter of Closed System Enterprises, what are your restrictions?

2. What is the functional purpose of your product?

3. What cups have you decided to use? Will you test what cups are best? Explain *why* you are choosing that particular combination or material.

4. Explain the method (the steps you took 1…, 2…, 3… etc.) your group will use to test the success of the design:

5. Sketches of design ideas:

6. Explain what Data you will collect to test the success of your prototype. Over how many minutes will your test last? *Make sure you have adequate amounts of data so you can make a graph and submit it to Mr. Imeter to review. Attach your data sheet and completed graph to this lab before passing in.*

7. How will you know whether or not your design was good?

Conclusion:

Write a letter to Closed System Enterprises. Your letter should include…

____ an explanation of what you did, what your results were, and why your design should be (or shouldn't be) chosen above all others
____an explanation of the independent and dependent variables in this challenge
____a Claim about what design (as well as materials) would be best for this challenge
____Evidence that supports your claim *(using your data)*
____ an explanation of your Reasoning *(how does your evidence support your claim? What could you have done to improve your design?)*

Dear Closed System Enterprises ,

APPENDIX F

STUDENT SURVEY

Participation in this research is voluntary and participation or non- participation will not affect a student's grade or class standing in any way. Please circle your selection and add comments to the questions that follow.

1. I prefer a science class with hands-on activities and labs.

5	4	3	2	1
strongly agree	agree	neutral	disagree	strongly disagree

What were some of your favorite activities we have done in this class so far?

2. I do not learn best by taking notes about the material.

5	4	3	2	1
strongly agree	agree	neutral	disagree	strongly disagree

3. I learn best by doing labs about the material.

5	4	3	2	1
strongly agree	agree	neutral	disagree	strongly disagree

4. The material I'm learning in class is not relevant to my life.

5	4	3	2	1
strongly agree	agree	neutral	disagree	strongly disagree

Why did you answer the way you did in the above question?

5. In this class, focus questions guide the labs.

5	4	3	2	1
strongly agree	agree	neutral	disagree	strongly disagree

6. When I do labs in this class, I get to use equipment and other science instruments often to collect data.

5	4	3	2	1
strongly agree	agree	neutral	disagree	strongly disagree

7. I prefer recipe-like lab instructions to follow step-by-step.

5	4	3	2	1
strongly agree	agree	neutral	disagree	strongly disagree

Why did you answer the way you did in the above question?

8. I prefer open-ended labs, where I have more freedom to decide how to run the experiment and have fewer directions to follow.

5	4	3	2	1
strongly agree	agree	neutral	disagree	strongly disagree

Why did you answer the way you did in the above question?

9. When I do labs in this class, I get to decide what data to collect or how to collect data.

5	4	3	2	1
strongly agree	agree	neutral	disagree	strongly disagree

10. When answering an analysis question, I do not know how to explain my reasoning using evidence from my data.

5	4	3	2	1
strongly agree	agree	neutral	disagree	strongly disagree

11. I am given opportunities to discuss my ideas in small groups.

5	4	3	2	1
strongly agree	agree	neutral	disagree	strongly disagree

12. I am not given opportunities to present my ideas through writing, drawing, or thinking.

5	4	3	2	1
strongly agree	agree	neutral	disagree	strongly disagree