

IMMERSING STUDENTS IN AUTHENTIC EXPERIENCES AND SCIENTIFIC
PRACTICES TO INCREASE ACHIEVEMENT, MOTIVATION,
AND ATTITUDES TOWARDS SCIENCE

by

Matthew Rath Fisher

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

©COPYRIGHT

by

Matthew Rath Fisher

2016

All Rights Reserved

TABLE OF CONTENTS

1. INTRODUCTION	1
2. CONCEPTUAL FRAMEWORK	2
3. METHODOLOGY	7
4. DATA AND ANALYSIS	20
5. INTERPRETATION AND CONCLUSION	30
6. VALUE	34
REFERENCES CITED.....	37
APPENDICES	42
APPENDIX A Laboratory Instructions for Students.....	43
APPENDIX B Lab Materials and Instructions for Preparation	46
APPENDIX C Institutional Review Board Approval.....	49
APPENDIX D Biology Motivation Questionnaire II	51
APPENDIX E Survey Regarding the Nature of Science.....	53
APPENDIX F Interview Questions	55
APPENDIX G Interview Transcripts.....	58
APPENDIX H Content Assessment	65
APPENDIX I Summary of Responses from Post-Intervention Interviews	70

LIST OF TABLES

1. Scientific Practices as Described by the National Research Council	8
2. Summary of Lab-Related Activities Occurring during the Water Treatment Unit	9
3. Summary of Lecture-Related Activities that Focused on Scientific Practices	12
4. Data Triangulation Matrix	15
5. Comparison of Means for the Five Subscales of the Biology Motivation Questionnaire II	22
6. Likert Items from the Biology Motivation Questionnaire II (BMQ II) and Nature of Science Survey (NOSS) for which the Median Response Changed.....	23
7. Cronbach's Alpha and Comparison of Means for the Nature of Science Survey ($N=11$).....	24

LIST OF FIGURES

1. Results from the Biology Motivation Questionnaire II	21
2. Boxplots for the Nature of Science Survey.....	25
3. Boxplots for the Content Assessments	27
4. Boxplot of Normalized Gain on the Content Assessment	28
5. Scatterplot Comparing Motivation and Normalized Gain	29
6. Comparison of Normalized Gain on the Content Assessment between Students with Decreased Versus Increased Motivation	29

ABSTRACT

Efforts to reform science education focus on implementing constructivist teaching strategies and engaging students in scientific practices. This paper assessed how implementing these strategies affected student achievement, motivation, and views towards science in a community college biology course for non-science majors. The intervention consisted of lecture and lab activities spanning the entire semester. The lab activities required students to collect, analyze, and interpret data and communicate their results. A special lab unit towards the end of the semester included field trips and inquiry-based labs that all focused on the topic of water treatment.

Data for this study were collected in the form of surveys, assessments, interviews, and teacher observation. Survey results indicated that the intervention had no significant change on students' levels of motivation or views towards science. However, all students interviewed reported that the class increased their understanding of the nature of science, especially as it relates to empiricism. In addition, opinions expressed during student interviews regarding motivation were positive about the fieldtrips and lab experiments; therefore, results from interviews and surveys were sometimes contradictory. Likert items for the nature of science survey developed specifically for this study were highly correlated to one another. Students demonstrated remarkable and statistically significant gains in content knowledge after the intervention. The results from this study should be viewed cautiously due to the low sample size and the lack of a control classroom. However, they do provide meaningful information about what aspects of the intervention can continued to be used and which need modification.

INTRODUCTION

Motivating students to excel in science courses is a perennial challenge faced by educators. College science courses are challenging, in part, because they introduce new concepts and terminology that require persistence by the student to master. Engaging students is especially challenging when those students are non-science majors who are mandated to take a science course as a general education requirement. In my current appointment at Great Falls College Montana State University (GFC MSU), I teach both science and non-science majors. For both sets, I have observed that GFC MSU students are more likely to struggle with learning course content than students at other colleges at which I have taught. At GFC MSU I have observed a greater proportion of students who have low motivation to excel academically, low interest in course content, and deficiencies with the study skills and discipline needed to succeed. This low achievement is demonstrated by the following statistic: During fall semester of 2014, just 25% of students enrolled in my introductory human biology course completed the semester with a grade higher than a D.

The reasons why students at GFC MSU struggle with achievement are speculative, but they could be influenced by socioeconomic variables. In comparison to the previous institutions at which I taught, the median wage in Great Falls is substantially lower, more students qualify for financial aid, and a greater percentage of students are the first in their family to attend college. Additionally, a greater percentage of students have interests outside of school that strongly compete for their time, such as children and/or

jobs. Clearly, these students face unique challenges and can be considered to be an at-risk student population.

To date, I have struggled to reach these students and felt outmatched by the challenges that they present to me. This made me wonder if changing my instructional methods would translate into increased student engagement and participation, so that motivation, learning, curiosity, and critical thinking increased. I was motivated to conduct this study by a desire to positively impact my students using constructivist teaching practices that immerse students in the process of science. My main research question was, “How will implementing active-learning strategies that focus on engaging students in scientific practices, such as inquiry, increase student achievement, motivation, and attitudes towards science?”

CONCEPTUAL FRAMEWORK

There has been much discussion in the last two decades about reforming science education (e.g., Ahlgren, 1996; Wheeler, 2006). The consensus that has emerged is that reform should be based on constructivist teaching practices (National Research Council, 2012). Inquiry-based instruction is one such constructivist strategy. It is a core tenet in the reform of science education and is promoted as a leading method for teaching science (National Research Council, 2012).

The roots of modern constructivist theory date back approximately 300 years ago to Henrich Pestalozze (1746–1827), and subsequently to Jean Piaget (1896-1980). The latter of these two is most frequently credited with fully developing constructivist philosophy (Crowther, 1999). Constructivism is defined by Hartle, Baviskar, and Smith

(2012) as “a theory that describes learning as taking new ideas or experiences and fitting them into a complex system that includes the learner’s entire prior learning” (p. 31).

Because learners must assimilate new information with old information, constructivism is an inherently active process. Research on constructivism has moved it into the forefront of science education reform, where it serves as a theoretical underpinning for how people learn (Hartle et al., 2012).

The challenge that faces educators is using constructivist theory to direct pedagogy. Notably, Crowther (1999) summarizes several attempts to transform constructivist theory into practical applications for the classroom. For example, Wheatley (1991; as cited in Crothwer 1999) offers a problem-centered approach that consists of three elements: tasks, groups, and sharing. As students work together on problems, they not only participate in cooperative learning, but also metacognition as they compare their problem-solving to others in the class. Better yet, Saunders (1992) provides a more elucidated and compelling strategy based on a four-part framework: 1) investigative labs, 2) active cognitive involvement, 3) stimulating work in small groups, and 4) alternative assessments. While there are numerous strategies for creating a constructivist learning environment (Crowther, 1999; Hartle et al., 2012), no single strategy is likely to work best in all situations and for all grade levels. Therefore, individual instructors must find the strategy that best suits their students and learning objectives.

Constructivism is at the heart of science education reform (National Research Council, 2012) because it is regarded as the leading theory that explains how people learn

(Llewellyn, 2013). Despite the difference in opinions for how to implement constructivist theory in the classroom, many seem to agree that inquiry, in particular, is a key component. Students who engage in inquiry display inquisitiveness, pose questions, search for answers, and seek to understand “counterintuitive phenomena” (Llewellyn, 2013, p. 6). In inquiry activities, students collect and analyze data, make evidence based-conclusions, and communicate their findings. In other words, they engage in science practices much in the same way that scientists go about studying the world and generating new knowledge (National Research Council, 2012).

There is strong evidence that inquiry and other constructivist strategies improve student achievement. For example, in a meta-analysis of 225 studies, Freeman and colleagues (2014) found that in college courses that focused on active-learning, which includes inquiry, students performed substantially better than students enrolled in conventional, lecture-based courses. In some cases, while students involved in inquiry-based courses may not report a significant increase in grades, they do report positive increases in attitudes, the feeling that lab activities are more practically relevant and meaningful, they have greater confidence in their skills, and have more positive perceptions of how their studies relate to the world around them (Beck, Butler, & Burke da Silva, 2014; Tomasik et al., 2014).

Because inquiry-based activities involve collection of data, posing questions, and designing investigations, they are a natural fit for inclusion into the laboratory portion of science courses. Unfortunately, many educators may think that their lab activities are inquiry-based because they are hands-on, but these two things are not always

synonymous (Llewellyn, 2103). Many laboratory activities are deemed ‘cookbook’ or ‘recipe’ labs because students unthinkingly follow procedures that are designed to produce a single correct answer. These do not meet the constructivist criteria mainly because students are not actively engaged or invested in their work and do little reflection upon their own learning during the activity. The false notion that any hands-on lab activity is automatically inquiry-based appears to be common, at least in the biological sciences. In a meta-analysis, Puttick, Drayton, and Cohen (2015) analyzed 111 articles published between 2007 and 2012 in *The American Biology Teacher* journal. Interestingly, 40% of the studies claimed that their instructional methods were inquiry-based, but only half of those studies provided any evidence to support this because few could demonstrate active student engagement in inquiry.

Inquiry-based activities exist along a spectrum of student and instructor involvement (Moyer, 2012). In the lowest levels of inquiry, much of the inquiry investigation, such as development of research questions and methodology, are determined by the instructor. This is called guided inquiry, and as one meta-analysis found, it is the most common type of inquiry published in the biological sciences (Beck et al., 2014). In the highest levels, called open inquiry, nearly everything is initiated by the student. There is debate about which level of inquiry is the best (Eastwell and MacKenzie, 2009). Some argue that instructors should always strive for open inquiry, which in their view is the best type of inquiry because students have the largest degree of freedom. However, some point to the lack of evidence supporting any inherent advantages of open inquiry, and warn against overlooking the importance and

effectiveness of guided inquiry practices (Eastwell and MacKenzie, 2009). As an example, in a small study, Moyer (2012) found low achievement and high uneasiness among students engaged in open inquiry compared to guided inquiry.

Inquiry-based lab activities, even guided inquiry, tend to give students considerable freedom to be active learners. Students may be given a research question or problem by the instructor, but are asked to determine the experimental methodology and conduct their own analysis (Unsworth, 2014). Or, students might be guided through an experiment by an instructor, but then asked to use their new knowledge to develop a related follow-up experiment (Ketpichainarong, Panijpan, & Ruenwongsa, 2010). Even the simple act of having students design their own data table is enough to get them to critically think about what type of data they might expect to collect and determine the best ways to organize it (Llewellyn, 2013).

In sum, constructivism is accepted by science educators as the leading theory of how people learn. In this philosophy, learners acquire new knowledge only after they assimilate new facts and experiences with prior knowledge. Educational strategies that promote active learning and metacognition are inherently constructivist. Among these methods is inquiry-based learning, in which learners pose questions, collect data, make conclusions, and display inquisitiveness. Inquiry, therefore, models the process of science. The level of student freedom in the inquiry process is the difference between guided and open inquiry, the latter giving students more autonomy. Various studies have shown active learning, and inquiry-based activities in particular, to boost student achievement and attitudes.

METHODOLOGY

The intervention was administered to college students enrolled in an introductory biology course for non-science majors. The course, BIOB 101 Discover Biology, met 4 days a week for a combined weekly total of 2 hours and 50 minutes of lecture, 1 hour and 50 minutes of lab, and 50 minutes of review. The intervention took place over the first 15 weeks of the 16-week semester.

The broadly-defined learning objectives for this course, as developed by the Montana University System, are as follows:

- Develop an understanding of principal concepts of biology.
- Experience science as a process of problem solving.
- Experience science as a process of discovery and explore the balanced interdependency of life.

The course fulfills the general education requirements for a lab science course, which is often the primary reason for why students choose to take the class. Typically for these students, this is their first and perhaps last college science course. During this study, 14 students were originally enrolled but only 11 remained at the end of the semester. Data were used from only the 11 students who completed the course.

Because most students in this course are typically non-science majors, misconceptions about the process of science and scientific principles can sometimes occur. Additionally, some students can lack the confidence needed to succeed in a college-level science course. The intervention of this study sought to address these concerns through the use of constructivist, active-learning activities that immersed

students in scientific practices (Table 1). The activities occurring during the intervention can be classified by whether they occurred in the laboratory or lecture components of the course.

Table 1
Scientific Practices as Described by the National Research Council (2012)

Scientific Practices
Asking questions*
Developing and using models
Planning and carrying out investigations*
Analyzing and interpreting data*
Using mathematics and computation thinking
Constructing explanations*
Engaging in argument from evidence*
Obtain, evaluating, and communicating information*

Note. Asterisk denotes practices employed in this study.

Laboratory Activities

Activities occurring in the laboratory portion of the course took place both in and out of the lab room. Throughout the semester there were 12 distinct lab activities, which included 2 fieldtrips. Not included in this tally was a supplementary activity on construction and interpretation of graphs. I ensured that these lab activities would engage students in scientific practices by creating the handouts and instructions myself. For example, nine of the ten activities based in the lab room required students to collect and analyze data, and use those data to make evidence-based conclusions. The one activity that did not require students to collect data was instead used to familiarize students with procedures needed for a subsequent lab.

The last six weeks of the course included a special unit that focused on the topics of water treatment, microbiology, and bioremediation. Hereafter this is referred to as the

water treatment unit (Table 2), which began during the tenth week of the semester.

During that week, students were taken on a fieldtrip to the City of Great Falls wastewater treatment facility. A tour of the facility lasted about one and a half hours and highlighted primary and secondary treatment, removal and treatment of sludge, and disinfection of the effluent before discharging it back into the environment. Wastewater treatment was relevant to this class because it relies on bioremediation, specifically the use of bacteria to remove dissolved organic material from the water. An added benefit of the tour was that it provided a demonstration of how biology can be used in everyday life, in addition to letting students observe scientists and engineers in action.

Table 2
Summary of Lab-Related Activities Occurring during the Water Treatment Unit

	Activity
Week 10	Fieldtrip to wastewater treatment plant
Week 11	Guided-inquiry lab –wastewater samples
Week 12-13	Open-inquiry lab –samples chosen by students
Week 14	Fieldtrip to drinking water treatment plant
Week 15	Presentations of experimental results by students

The tour not only provided students an authentic experience, it was also necessary for completing the next activity: a guided-inquiry laboratory investigation. During the tour wastewater samples were collected in sterile containers at different points along the treatment process, including the primary clarifier, secondary clarifier, and at the outfall.

During week 11, students participated in a guided-inquiry lab experiment using those wastewater samples. This lab enabled students to quantify *Escherichia coli* levels in each sample. While the scope of the experiment and its methods were pre-determined, students were actively involved in the inquiry process in several ways:

determining the research questions and hypotheses, creating their own data tables, analyzing and interpreting their own data, and constructing evidence-based conclusions.

At the beginning of this activity, students were organized into small groups and informed that they had the capacity to measure *E. coli* numbers in the water samples. Knowing this, each group was instructed to brainstorm potential research questions that could be tested. The question that usually comes to most peoples' minds is, "How do *E. coli* levels differ among the water samples?" With testable questions identified, groups developed their hypotheses in the form of explanatory statements. By allowing students to create research questions and hypotheses, they become active participants and stakeholders in the investigative process.

Each group of students then tested their hypothesis while gaining experience using the multiple tube fermentation technique. This technique has real-world applications and uses a presumptive test, which provides evidence for the presence of bacteria, followed by a confirmative test, which positively identifies the bacteria as *E.coli* (Appendices A & B). For logistical reasons, each group of students received wastewater from only one of the three samples. At the end of the experiment, data were pooled from the entire class. Thus, students could work with the class data to test each group's hypothesis.

At the conclusion of this activity, students were given an assignment to assess their understanding of bioremediation in wastewater treatment and the theoretical underpinnings of the multiple tube fermentation technique. Additionally, they were

required to produce graphs of their results and to construct an evidence-based conclusion to assess their hypothesis.

During weeks 12 and 13, students engaged in an open inquiry lab investigation in which they conducted their own study. Continuing to work in small groups, they posed research questions, formed explanatory hypotheses, and created graphs of their predicted results. Students then planned their experimental design, which involved determining the location of their water samples and the method of procuring them. Their experimental designs were approved by me, allowing me to consider any potential safety issues, in addition to making sure that students used sterile technique. Once water samples were obtained the following week, students tested their hypotheses using the procedures previously described for the multiple tube fermentation technique.

With data collection concluded, students were given two weeks to complete their assignment for this activity. Student groups were asked to give presentations that followed the standard format for scientific research: introduction, methods, results, and discussion. The emphasis here was for students to analyze the data, make evidence-based conclusions using their data, consult the scientific literature to support their conclusion, reflect upon the validity of their hypothesis, and communicate their findings to others. Students were specifically instructed to identify the potential causes for any observed differences in *E. coli* levels between their water samples. Lastly, students were asked to present a suggestion for a follow-up study.

During week 14, the week prior to the group presentations, students were taken on a fieldtrip to the City of Great Falls drinking water treatment facility to give them

perspective at the opposite end of the water treatment spectrum. Drinking water treatment relies on physicochemical methods, not bioremediation. Regardless, the fieldtrip still exposed students to scientists and engineers in action, and further solidified how science permeates everyday life. Immediately following the hour-long tour, I engaged students in a group discussion in which we noted the differences between drinking water treatment and wastewater treatment.

Lecture Activities

Activities during lecture that were constructivist or meant to expose students to scientific practices ranged from videos to a debate (Table 3). All of these activities occurred during the last half of the semester, and many of them coincided with the water treatment unit occurring in lab. In this way, the overall intervention was concentrated from weeks 8 to 15.

Table 3
Summary of Lecture-Related Activities that Focused on Scientific Practices

	Activity
Week 7	HHMI video on evolution of birds
Week 8	Jack Horner TED talk
Week 10	NOVA video on human evolution discovery
Week 13	Cosmos video on scientific process
Week 14	Activity on identifying scientific statements
Week 15	Debate activity on alternative fuels

Students were shown four videos that not only delivered relevant content, but also exposed students to how scientists work and produce knowledge. The first was a 19-minute video published by the Howard Hughes Medical Institute that focused on visualizing fossil evidence to highlight the evolutionary link between dinosaurs and birds (Levitt & Carroll, 2015). The second video was a TED talk by Jack Horner (Horner,

2011), a renowned dinosaur paleontologist and professor at Montana State University. In the 16-minute video, Horner described scientific evidence and its meaning, in addition to how genetic tools can be used to expose the common ancestry between dinosaurs and birds. The third video was a two-hour episode of *NOVA*, a television series broadcast on PBS, called “Dawn of Humanity” (Townesley, 2015) that gave an excellent look at the process of scientific discovery. The video highlighted the efforts that went into finding and extracting fossils of a new hominin species named *Homo naledi*. The final video shown to students was an episode of the television mini-series, *Cosmos: A Space Odyssey*, called “The Clean Room” (Druyan, Soter, & Braga, 2014). This 45-minute video highlighted efforts by scientist Clair Patterson to date the age of the Earth. The video provides a superb view into the process of science and the determinedness and integrity of Patterson’s character.

During week 14, students participated in an in-class assignment designed to increase their understanding of what constitutes scientific knowledge. This activity provided opportunities for students to evaluate ways in which information is produced, understand criteria for what distinguishes science from other ways of knowing, and evaluate claims as scientific or non-scientific based on the aforementioned criteria. This activity was adapted from Bramschreiber and Westmoreland (2015).

The final activity was an inquiry-based debate on alternative energy, which corresponded to the lecture topic of global warming. This is an inquiry-based activity because students collect information, make conclusions, and engage in scientific argumentation. Students were organized into four groups. Half of those groups were

assigned the topic of nuclear energy and the other half were assigned the topic of bioethanol. The two groups for each topic debated each other, however, they were not told whether they would be arguing the pro or con side until the day of the debate. As such, a week before the debate students were instructed to research both the pro and con sides, using credible references, and to turn in an annotated bibliography. On the day of the debate, I randomly assigned each group to either the pro or con viewpoint and then gave them 15 minutes as a group to prepare. The actual debate consisted of opening statements and one round of rebuttals, followed by a brief class discussion. Prior to introducing the assignment, I informed students that argumentation is important to the scientific process. But unlike people such as politicians, who argue mostly based on ideology, scientists rely on facts. They were instructed to debate using fact-based arguments.

Data Collection

To evaluate the intervention, multiple lines of evidence were collected throughout the study period (Table 4). Information was gathered using multiple modalities that included tests, surveys, interviews, and observations. Data on content knowledge and student attitudes were collected from a single class containing 11 students. Prior to conducting this research, approval was granted by Montana State University's institutional review board (Appendix C). All statistical analysis was performed using SPSS software.

For practical reasons, the experimental design of this study did not include a control. Ideally, a second classroom would be used as a control if it covered the same

material but did not focus heavily on engaging students in scientific practices. However, this would have required me to teach at least two sections of the same course during the study period, which was not possible. Lacking a control, this study does not have the ability to address the question of whether constructivist teaching methods are superior to traditional methods. However, the study does allow me to see if this curriculum, in itself, is effective in reaching its goals of increasing student motivation, increasing positive and more comprehensive attitudes toward science practices, and increasing relevant content-knowledge.

Table 4
Data Triangulation Matrix

Research Question	Data Source 1	Data Source 2	Data Source 3
How has student motivation and interest changed?	Pre- and post-intervention surveys for motivation	Instructor observations of students	Post-intervention randomized student interviews
How have student attitudes towards the nature of science changed?	Pre- and post-intervention surveys for attitudes	Instructor observations of students	Post-intervention randomized student interviews
How was student content knowledge affected?	Pre- and post-intervention assessments	Proficiency status	

Surveys

Surveys were used to assess how semester-long engagement in scientific practices and active learning changed student motivation and views towards science. For this, I administered two types of surveys: one to assess students' perception of motivation and one to assess attitudes towards the nature of science. Both of these surveys were administered together and given to all students both at the start and the end of the semester. This method provided me the opportunity to detect changes in attitudes as a

result of the intervention. Each submission was coded with a unique number to keep track of respondents and to maintain their anonymity.

To assess student motivation, I used a validated instrument called the Biology Motivation Questionnaire II (BMQ II; Appendix D; Glynn, Brickman, Armstrong & Taasoobshirazi, 2011). Permission to use this copyrighted survey is granted to educators that agree to comply with fair-use. This survey contained 25 Likert items organized into five subscales:

- intrinsic motivation, items 1, 3, 12, 17, and 19;
- self-efficacy, items 9, 14, 15, 18, and 21;
- self-determination, 5, 6, 11, 16, and 22;
- grade motivation, 2, 4, 8, 20, and 24;
- career motivation, 7, 10, 13, 23, and 25.

The second survey that I used is a non-validated instrument that I developed to assess students' attitudes towards the nature of science, hereafter referred to as the nature of science survey. I was unable to find a validated instrument that fit my class and the objectives of this study. Instead, I consulted literature on the nature of science (e.g., McComas, 2015) as well as validated instruments to develop my own survey. I took inspiration, in particular, from the instrument developed by Liang et al. (2008), even though I did not feel that their questions measured the specific items that I felt were relevant to my study.

The nature of science survey (Appendix E) included 12 Likert items that fall into three subscales. These are listed below, in addition to the Likert items that belong to each:

- Science is empirical: items 5, 7, 8, and 9;
- Scientific knowledge has limits: items 2, 4, 10, and 12;
- Scientific knowledge is tenable: items 1, 3, 6, and 11.

Thus, each subscale has four statements to assess one particular underlying construct, which is the same theoretical format used by Liang et al. (2008).

To help validate the nature of science survey, I calculated Cronbach's alpha (such as in Liang et al., 2008) for the entire survey, in addition to each of the three subscales mentioned above. Cronbach's alpha is a measure of internal consistency and measures how well Likert items correlate to one another (Laerd Statistics, 2013). Only if a particular value was equal to or above 0.55 was I able to treat each category as a unified Likert scale (Hatcher & Stepanski, 1995), which then allowed me to use statistical tests.

Responses for each Likert item were assigned values, zero to four and one to five for the BMQ II and NOS survey, respectively. Scores were created by summing these values and expressing it as a percentage of the total maximum points available. Scores from the pre- and post-intervention surveys were compared using one-way ANOVA when data met the assumptions of the test, such as normality and homogeneity of variance. If they did not, I used the non-parametric Mann-Whitney U-test because it does not rely on underlying assumptions regarding the nature of the data. Further

analysis included comparing individual Likert items between pre- and post-surveys by simply comparing differences in median responses, without statistical testing.

Interviews

Students' perceptions of motivation and attitudes towards the nature of science were also assessed by administering post-intervention interviews. To achieve this, 5 of the 11 students were randomly selected for an interview. Random selection occurred by arbitrarily assigning students a number and then using a random number generator in Excel to select the interviewees. I chose random selection because it allowed me to extrapolate my results to the rest of the class.

The interview questions that I used were open-ended (Appendix F). This allowed students to provide a variety of responses, some of which I was unable to anticipate. I was concerned that interviewees might give me answers that they felt were "right", as opposed to their honest opinions. To help counteract this, a colleague of mine conducted the interviews on my behalf. These interviews were audio recorded with the interviewee's consent. The interviews were treated as a five-point assignment as motivation to participate. Students who were not randomly selected for an interview were given an alternate five-point assignment. The interviews were conducted in private, away from me and the rest of the class.

The interview questions for the topic of motivation (Appendix F) were deliberately written to get students to think about the specific elements of class that changed their levels of interest and motivation in biology. Two of the questions involved the topic of relevance. From my experience, the more relevant the material and activities

are, the greater the interest and motivation from students. Therefore, relevance and motivation are interrelated.

The interview questions that probed students' attitudes on the nature of science (Appendix F) were written to explore two things: 1) their current perceptions of how science works, and 2) how this class has changed their viewpoints towards the nature of science.

Data collected from the interviews were transcribed and entered into a Word file (Appendix G). I searched for patterns among the respondents by looking at reoccurring themes, ideas, and terms. I also looked for interesting or unique insights that provided additional information that enabled me to assess the effectiveness of my intervention, or gave me ways to improve curriculum for future classes.

Content Assessment

While the surveys were used to detect changes over the entire semester, the content assessment was used for the last six weeks of semester only, which corresponded to the water treatment unit occurring in lab. To objectively assess how effective that curriculum was at promoting student learning, a pre-assessment was given at week 9 while a post-assessment was administered at week 15. These identical assessments were comprised of 18 multiple-choice and two short-answer questions that covered topics of biochemistry, bioremediation, nutrient cycling, and wastewater treatment (Appendix H). A key innovation employed for this assessment was use of an "I don't know" option for all questions. Students were instructed to select this if they were unsure of an answer. This allowed for a more accurate reflection of students'

knowledge because it eliminated correct responses due solely to guessing. Overall scores were calculated for each test, and differences for each student between the pre- and post-assessments were calculated using normalized gain (Hake, 2002). Students were deemed to show content proficiency of the content with a minimum score of 70%.

Difference between pre- and post-assessments were statistically tested using one-way ANOVA, assuming that the data met the assumptions of this test. In circumstances where the data did not meet these assumptions, I utilized the non-parametric Mann-Whitney U test.

Instructor Observations

To supplement data collected from surveys on perceptions of self-motivation and views towards science, I collected observations of the class. I wrote journal entries once a week in which I recorded observations of student-to-student interactions, student to teacher interactions, behaviors and body language exhibited during class, and questions asked either during class or by email. These observations were analyzed by looking for particular trends, unique or extraordinary student behaviors, and for correlation between my observations and events that occurred during the intervention.

DATA AND ANALYSIS

Students' motivation and attitudes towards science were assessed by surveys administered prior to and after the semester-long intervention. Levels of motivation, in particular, were determined by use of the Biology Motivation Questionnaire II (BMQ II; Gylmn et al., 2011). While a decrease of 1.54% in overall motivation was observed in

post-intervention scores (Figure 1), this difference was not significant (ANOVA; $p = 0.721$).

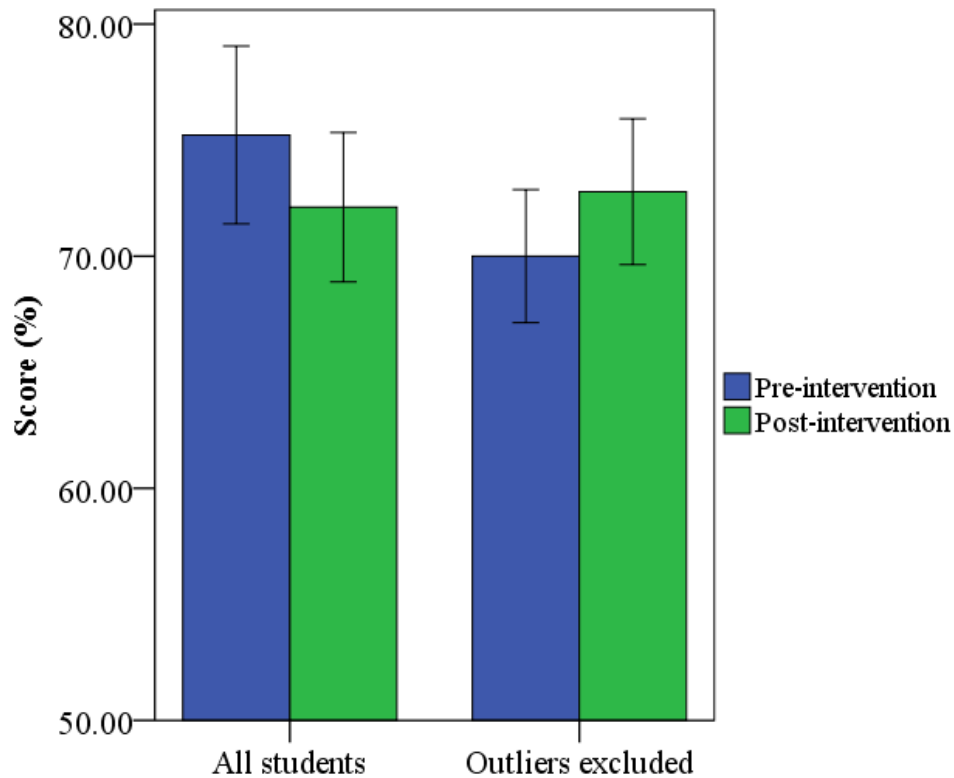


Figure 1. Results from the Biology Motivation Questionnaire II (Gylmn et al., 2011). No significant differences were found in either case; *All students*: ANOVA; $p = 0.721$, $N = 11$; *Outliers excluded*: ANOVA, $p = 0.523$, $N = 9$.

Five of 11 students exhibited a decrease in their overall post-intervention score for the BMQ II, while the remaining 6 showed an increase. The average change for those showing a decrease in scores was 12%, while those demonstrating an increase in score had an average change of 8%. These differences were not statistically significant (U test; $p = 0.931$). Two students had exceptionally large changes and therefore contributed strongly to the results. Students #3 and #9 showed decreases of 25% and 23%, respectively. These changes are more than twice that of any other student. Notably, both

of these students were randomly chosen for interviews and gave statements indicating no change in their motivation. Specifically, student #9 stated, “I don’t think that my motivation has really changed,” while student #3 remarked, “[the class] didn’t really decrease my motivation it just, I didn’t see it being as easy as I thought it was going to be.” Interestingly, both students reported exceptionally high scores on the pre-intervention survey: 84% and 94%. If data from these two students are excluded then a slight increase of 3% between pre- and post-intervention scores was seen (Figure 1). This difference, however, is also not significantly different (ANOVA, $p = 0.523$).

Results for the five subscales of the BMQ II exhibited no statistically significant changes as a result of the intervention (Table 5). Three of the subscales exhibited slight non-significant decreases while the remaining two showed slight non-significant increases. Of the five subscales, the one measuring career motivation was about 30% lower than the subscale with the next highest score.

Table 5
Comparison of Means for the Five Subscales of the Biology Motivation Questionnaire II

Subscale	Mean % (standard error)		p value
	Pre-intervention	Post-intervention	
intrinsic motivation	80.0 (3.16)	75.0 (5.35)	0.431
self-efficacy	75.5 (5.15)	72.7 (3.78)	0.674
self-determination	75.0 (3.50)	70.5 (4.18)	0.478 ^U
grade motivation	80.5 (5.02)	86.4 (3.44)	0.343
career motivation	53.4 (6.18)	55.0 (6.43)	0.898 ^U

Note. Statistical analysis done using one-way ANOVA, except where noted with superscript. U = Mann-Whitney U test, used because distribution was non-normal.

Median responses between the pre- and post-intervention BMQ II were analyzed for changes and are summarized in Table 6. Just 5 of the 25 Likert items exhibited a

change. Three had a negative change (lower motivation) and the remaining two showed positive change (greater motivation). Some of these results are contradictory. For example, greater motivation was indicated for Likert item #15, “I believe I can master biology knowledge and skills,” while there was a decrease in motivation for Likert item #18, “I believe I can earn a grade of “A” in biology”. In some cases the results are complimentary. For example, there was a decrease in both Likert items #3 and #19, which are, “Learning biology is interesting,” and, “I enjoy learning biology,” respectively (Gylmn et al., 2011).

Table 6

Likert Items from the Biology Motivation Questionnaire II (BMQ II) and Nature of Science Survey (NOSS) for which the Median Response Changed

		Likert item					
	BMQ II	#3	#8	#15	#18	#19	
Response	Pre	Always	Often	Sometimes	Always	Always	
	Post	Often	Always	Often	Often	Often	
		Likert item					
	NOSS	#2	#3	#5	#7	#8	#9
Response	Pre	SA	A	A	A	SA	A/SA
	Post	A	SA	SA	SA	A	SA

Note. Pre = before the intervention; Post = after the intervention; A=strongly agree; SA=strongly agree; A/SA= halfway between agree and strongly agree. See appendices D and E for full text of each Likert item.

The nature of science survey was used to assess changes in students’ views towards science as a result of the semester-long intervention. This survey was a non-validated instrument created by me specifically for this study. To help validate the instrument, I calculated Cronbach’s alpha for the entire survey in addition to each of the three subscales. The minimum value for all results was 0.699, well above the minimum

threshold of 0.55 for validity (Table 7). This indicates high correlation, or internal consistency, among the Likert items of the survey. These results indicated that I could proceed with further analysis.

Table 7
Cronbach's Alpha and Comparison of Means for the Nature of Science Survey (N=11)

	Cronbach's alpha			Comparison of means (%)		
	pre-intervention	post-intervention	avg.	pre-intervention (SE)	post-intervention (SE)	p value
Overall	0.878	0.854	0.866	77.8 (3.27)	82.9 (2.95)	0.269
Empirical	0.819	0.760	0.790	82.7 (4.59)	89.1 (3.68)	0.401 ^U
Limits	0.725	0.755	0.740	70.0 (4.52)	71.8 (4.28)	0.773
Tenable	0.708	0.690	0.699	80.9 (3.36)	87.7 (3.26)	0.161

Note. Cronbach's alpha values over 0.55 indicate a significant correlation (Liang et al., 2008). "Overall" summarizes the summed scores for all survey questions. The following are subscales: "Empirical" = questions 5 and 7- 9; "Limits" = questions 2, 4, 10, and 12; "Tenable" = questions 1, 3, 6, and 11. "SE" = standard error; "U" denotes use of the non-parametric Mann-Whitney U test because data failed test of normality.

I found that average scores from the nature of science survey did not change as a result of the intervention (Figure 2). Mean scores were slightly higher for the post-intervention surveys, including the entire survey plus each of the three subcategories, but these differences were not statistically significant (Table 7). All survey scores, whether pre- or post-intervention, were relatively high in the 70% - 90% range. Unlike the survey assessing motivation, only one person exhibited a decrease in their post-intervention score. This person, student #9, was one of the two students that reported an exceptionally large decrease in their motivation score. One student reported no change in score, while the remaining nine showed an increase. The average change in score was +5%.

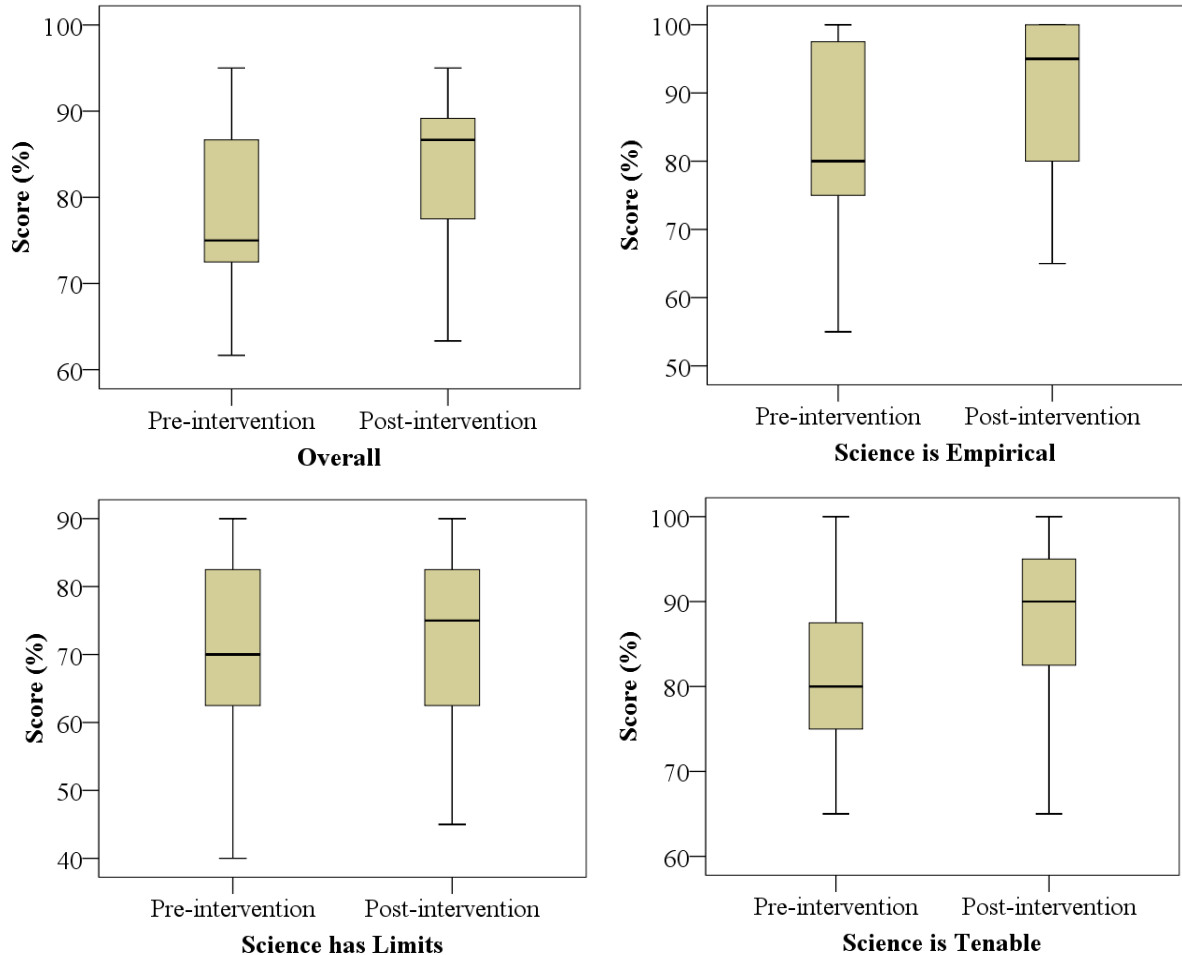


Figure 2. Boxplots showing median, first and third quartiles, and range for the nature of science survey administered to students, ($N=11$). Clockwise from top left: "Overall" summarizes the summed scores for all survey questions; "Science is Empirical" summarizes question 5, 7, 8, and 9; "Science is Tenable" summarizes questions 1, 3, 6, and 11; "Science has Limits" summarizes questions 2, 4, 10, and 12. Statistical tests for each of the above pairwise comparisons found no significant differences (see Table 6).

Median responses on the pre- and post-intervention nature of science survey were also analyzed for changes and are summarized in Table 6. Six of the 12 Likert items exhibited such a change. Two had a negative change (less understanding) and the remaining four showed positive change (greater understanding). For example, the median response for the statement, "scientific knowledge is not intended to be an authority on

matters of spirituality and morality,” changed from “strongly agree” to “agree” following the intervention.

The nature of science survey is similar to the Biology Motivation Questionnaire II in that some of the results appear to contradict one another. For example, students demonstrated a stronger belief that, “scientific knowledge is strictly based on information that be measured and verified,” while concurrently showing decreased agreement with a statement that said, “scientific knowledge cannot be produced without data collected through observation and/or experimentation.”

All four Likert items in the “science is empirical” subscale of the survey exhibited a change in the median response (items 5, 7, 8, and 9) following the intervention. In comparison, each of the other two subcategories had only one Likert item that changed. Of those Likert items in the “science is empirical” subcategory, three exhibited a change towards a more positive response and one became more negative. Despite the contradictory results noted in the previous paragraph, the students interviewed clearly demonstrated an understanding of the importance of empiricism in science (Appendix I). For example, all five students interviewed indicated that the course increased i) their perception of how scientific knowledge is produced, ii) their ability to recognize scientific statements, iii) the perceptions of science as fact-based, and iv) their skepticism of those that present conclusions that are not evidence-based. Student #8’s response in the interview is indicative of the other interviewees’ responses,

You don’t have to be a scientist, but you can’t just take everything for face value. You want to look into it and investigate it ...and I do that more now because of this class than I did at the start.

A pre- and post-intervention assessment was administered to assess changes among students in content knowledge due specifically to the water treatment unit that occurred during the last six weeks of the semester. Students demonstrated a large, statistically significant increase (U test, $p < 0.001$) in their scores following the intervention (Figure 3). The average score increased from 14% before the intervention to 80% after it.

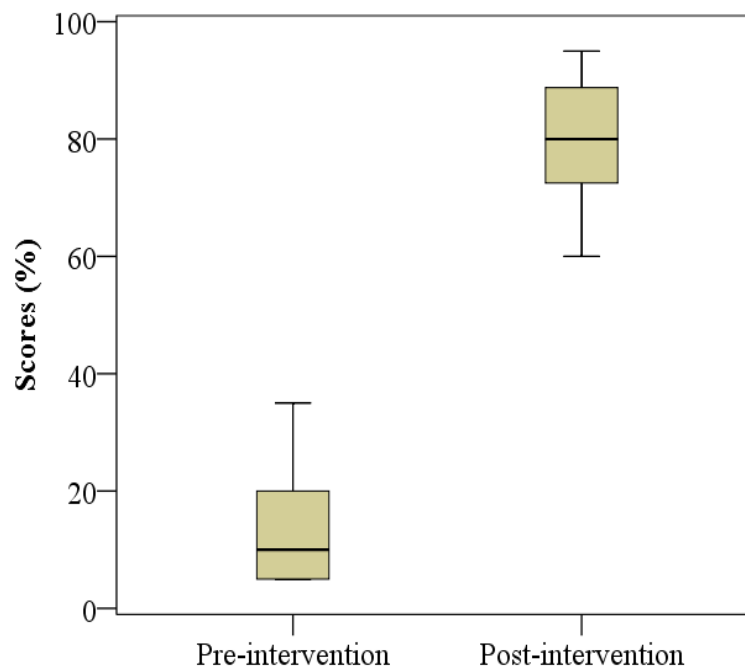


Figure 3. Boxplots showing median, first and third quartiles, and range for the content assessments, ($N=11$). The non-parametric Mann-Whitney U test was used because data were non-normal. A significant difference was found between the pre- and post-assessment ($p < 0.001$).

The average normalized gain between the pre- and post-intervention assessment was 0.75 (Figure 4). This indicates that, on average, students earned 75% of the maximum increase possible. Regression analysis between normalized gain and motivation, as measured by post-intervention BMQ II scores, found no relationship ($R^2 = 0.072$, $p = 0.426$; Figure 5). Similarly, there was no significant difference in normalized gain between students with positive or negative changes in motivation (Figure 6). The mean normalized gain for students with increased motivation was 80%, while those with decreased motivation had a mean of 70%, a non-significant difference (ANOVA, $p = 0.347$).

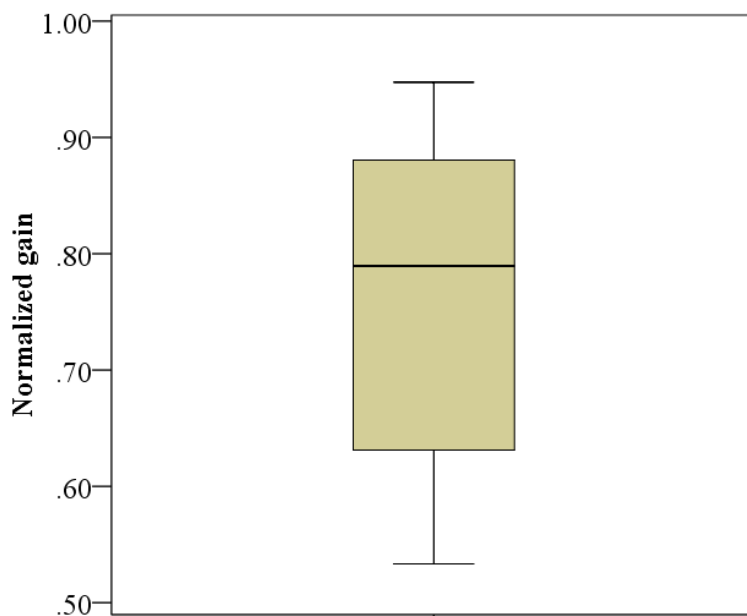


Figure 4. Normalized gain between the pre- and post-test for content knowledge, ($N=11$). Boxplot shows median, first and third quartiles, and range for the content assessment.

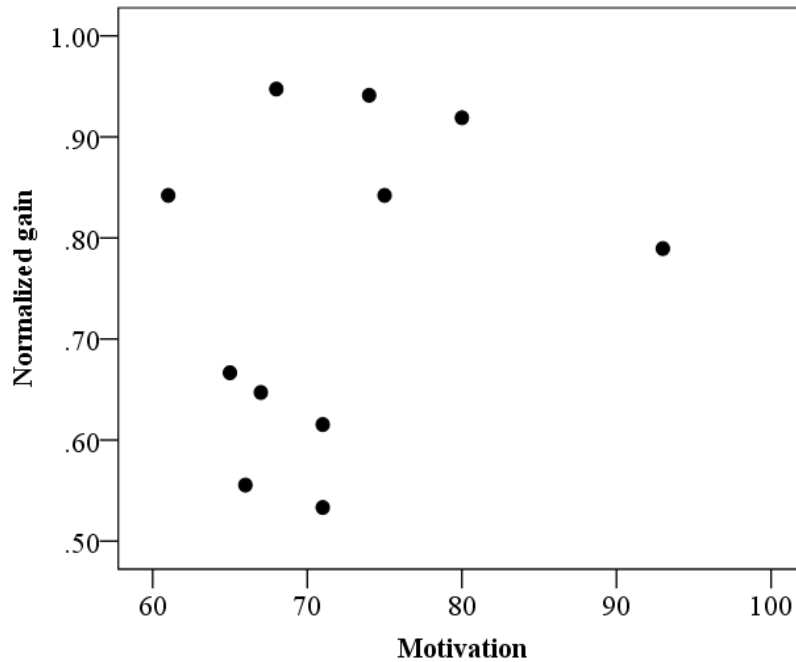


Figure 5. Scatterplot comparing motivation, as measured by post-intervention BMQ II scores, and normalized gain on the content assessment, ($N = 11$). Regression analysis: $R^2 = 0.072$, $p = 0.426$.

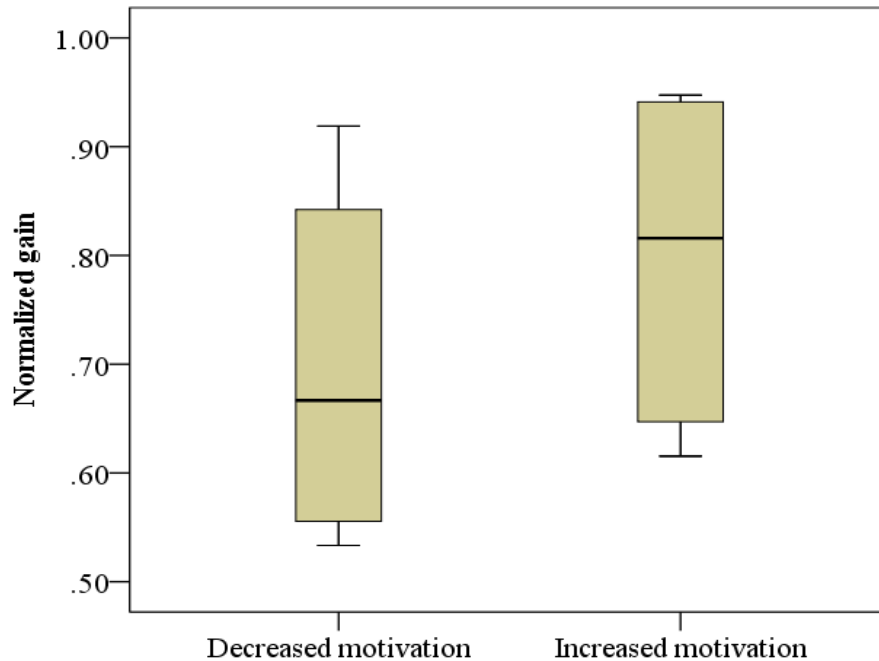


Figure 6. Comparison of normalized gain on the content assessment between students that reported a decrease, ($N = 5$), on the BMQ II versus those that reported an increase, ($N = 6$). No statistically significant difference was discovered between the two groups ($p = 0.347$). Boxplots show median, first and third quartiles, and range.

When asked during the interviews what caused their interest in biology to increase, students most frequently mentioned the activities of the water treatment unit (Appendix I). Of the five students interviewed, four said that the field trips increased their interest, three mentioned the inquiry-based water quality experiments, and one person mentioned the *NOVA* video on human evolution that was shown during lecture. Student #9 said, “I think in some ways it [the class] raised my level of interest in biology, especially when we went to the wastewater treatment because it kind of showed a different side that I hadn’t been previously exposed to.”

During the interviews, students were also asked how class affected their perception of biology’s relevance. Again, the activities of the water treatment unit were the most commonly mentioned (Appendix I). For example, all five students interviewed mentioned the field trips. Student #9 added,

It definitely opened my eyes, a little more I think. When you’re not going into a science specific field or something that is going to deal with science heavily later on in a career, you go a little bit blind to ways the science is used in everyday life, like the wastewater treatment for example. I don’t think many people know what goes on there until you’ve actually gone there and explored it.

Students also attributed lecture-based activities to increasing their perceptions of biology’s relevance. Specifically, units on global warming, human evolution, and genetics were all mentioned.

INTERPRETATION AND CONCLUSION

A primary goal of this study was to determine how immersing students in scientific practices impacted motivation and views towards science. Anecdotal evidence from previous semesters suggested low motivation and poor scientific literacy because most or all students were non-science majors. Studies have shown that non-science

majors report lower motivation (Glynn et al., 2011; Shell & Soh, 2013) and can demonstrate lower understanding of the nature of science when compared to science majors (Lin, 2014). Motivation is important because it is a key factor to student success (Schunk, Pintrich, & Meece, 2008; as cited in Schumm & Bogner, 2016), whereas understanding the nature of science (NOS) leads to traits such as skepticism and critical thinking, cornerstones of scientific literacy (Lin, 2014).

In this study, the intervention appeared to have little impact on motivation and views towards science. Surveys administered before and after the intervention indicated no statistically significant change for both of these variables. In regard to motivation, the class was split as approximately half increased in motivation while the other half decreased. Meanwhile, 10 out of 11 students showed non-significant gains for the NOS survey and 1 student exhibited a decrease. These results are not without precedent. At least one other study found no gain in motivation following an intervention consisting of constructivist pedagogy (Cetin-Dindar, 2016).

Results from both types of surveys in the present study are viewed with some uncertainty, however, because of particular contradictions. For example, motivation scores for two students profoundly decreased by more than 20%, but in the interviews both students said that their motivation levels did not change over the semester. Similarly, all students interviewed acknowledged that the class increased their understanding of the NOS in at least one way, yet the differences between the pre- and post-intervention surveys were not statistically different. Furthermore, one student interviewed indicated that the class helped increase her understanding of NOS, but

nevertheless her NOS survey score decreased by 7% following the intervention. In addition, I found contradictions within the survey results. On the BMQ II, for example, I found the median response for one particular Likert item increased, while the median response for a Likert item with nearly identical meaning decreased.

These issues raise doubt as to how accurately the interviews and/or surveys captured viewpoints. The interview questions may have been too simplistic to fully assess the complex constructs underlying motivation and views towards science. The survey scores also appeared to be exceptionally high. When I collected the pre-intervention BMQ II survey, in particular, I was immediately struck by the high scores. I suspected at the time, and still do, that some students were not entirely truthful and instead provided answers that they imagined would please me. The class average on the survey was 74%, quite high for non-science majors taking their first college-level science course. In comparison, Glynn et al. (2011) found that when validating the BMQ II the average scores for 313 non-science majors was 63%. Additionally, Schumm and Bogner (2016) tested 232 10th graders in a German college-preparatory school and found an average score of 61%. Clearly, scores in the present study are inflated and possibly inaccurate, which may have obscured the detection of meaningful trends.

In addition to these concerns, the small sample size of this study ($N = 11$) is problematic. While anomalous results, like those described above, are not uncommon in a study, the impact that they have on the results is typically masked by a sufficiently large sample size. In this study, the sample size was not large and therefore these

anomalies could have substantially biased the results. This could be remedied by pooling data from future classes that receive the same intervention, and then re-analyzing it.

While there was little evidence in this study for change in both motivation and views towards science due to the intervention, students interviewed did indicate that the class impacted them in positive ways. For example, many students indicated that lab activities, notably the fieldtrips, increased their motivation and helped them to see how biology is relevant to their lives. One student described an enthusiasm for the open inquiry lab experiment and the intellectual freedom it provided. Additionally, all students interviewed demonstrated proficiency in certain aspects of scientific literacy, such as skepticism and the importance of empiricism. It is likely that the semester-long habit of collecting and analyzing data in lab, in addition to constructing evidence-based explanations, contributed to this. In addition, two of the five students interviewed specifically attributed the in-class activity on identifying scientific statements as having increased their skills in this regard. Lastly, during the interviews students referenced some of the videos shown during lecture that highlighted how scientists go about collecting and interpreting evidence.

The other focus of this study was to determine how the water treatment unit affected students' achievement in content knowledge. I found that this portion of the intervention was very successful in increasing students' knowledge. The average score increased from 14% to 80%, which is above the predetermined proficiency status of 70%. The average normalized gain was 0.75, a remarkable increase. It should be noted, however, that while this intervention was successful, the lack of a control group means

that I cannot conclude that the intervention worked better than any other type of pedagogy, including those that do not immerse students in scientific practices and utilize constructivist methods.

The large gains in content assessment scores may be attributed to the authentic nature of the water treatment unit. This part of the intervention included two fieldtrips and two inquiry-based lab experiments, each with real-world implications. Students indicated in the interviews that they found these activities motivating and relevant. Relevance (Glynn, et al., 2011) and authenticity (Hursen, 2016) positively contribute toward motivation, and motivation is important to student achievement (Chow & Yong, 2013). A link between motivation as measured by the BMQ II and performance on the content assessment was not observed in this study, however. Regression analysis showed no relationship between normalized gain and BMQ II scores. Additionally, no difference in normalized gain was found for students that exhibited increased versus decreased motivation.

VALUE

Particular aspects of the intervention were useful to students and should continue to be used in future classes. Information collected from interviews, content assessments, and through my own observation indicate that the water treatment unit, in particular, was effective in promoting learning, motivation, and biology's relevance. The fieldtrips were especially important in this regard. While students seemed to enjoy the open-inquiry lab, I would like to expand the number of variables that students can test. Currently, students measure *E. coli* levels only, but I believe that giving them the opportunity to measure

other variables of their choosing, such as pH and nitrate levels, would increase their level of control and engagement in the experiment, promote deeper exploration of water quality issues, and reinforce content from lecture.

Through observation and interviews, I found that the lecture activities were also useful and will continue to be used. For example, the videos not only delivered content, they also showcased how scientists conduct research, which is important when teaching students about the nature of science (NOS). Students particularly liked the *NOVA* video on human evolution (Townesley, 2015). This video focused on the complicated process by which fossil evidence was collected. I thought students might get bored during the two-hour viewing, or be off-put because human evolution can be a contentious social issue, but neither were the case.

Substantial changes in motivation were not achieved in this study. Part of this may be due to inaccurate survey results. In the future, having someone else administer and collect the surveys, in addition to having students use a unique numerical code instead of their name, might give them the sense that the surveys are anonymous and thus lead to more truthful responses. The intervention should also be modified in ways to increase motivation and the water treatment unit can serve as a model for this. This unit was effective because students found it relevant and authentic, both of which can contribute towards motivation. Greater efforts should be taken in lecture, in particular, to highlight how content is applicable to their lives.

Modification of the intervention is also needed to enact greater gains in students understanding of the NOS. The present study relied on engaging students in scientific

practices and watching videos that highlighted the work of scientists. Johnson (2016)

argues that such an approach is not enough, stating that,

If we hope to develop scientifically literate citizens, science education must extend beyond content knowledge and scientific practices to uncover the values and habits of mind that are specific to science (p. 371).

Requiring students to actively reflect upon the values and habits of scientists may lead to a deeper understanding of the NOS. These reflections could be applied to videos or case studies that showcase scientists, in addition to students' own scientific endeavors in lab. Some aspects of the NOS were not explicitly addressed by me during the semester, such as the process of peer review. Spending more time in class, through instruction and reflection, will likely increase scientific literacy.

Overall, this study implemented constructivist teaching practices that promote active learning, such as inquiry-based labs, debates, and collaborative in-class assignments. I will continue to implement and refine constructivist techniques because it has been shown to positively affect many aspects of learning (Wood, 2009). Inquiry-based learning, in particular, is especially interesting to me because it promotes deep learning through the critical analysis of data (Minner, Levy, & Century, 2010). I want students to learn science by doing science and therefore will continue to implement inquiry-based strategies. Additionally, this study immersed students in scientific practices, as recommend by National Research Council (2012), and involved them in authentic experiences, as recommend by the American Association for the Advancement of Science (2011). As I move forward I will strive to improve student outcomes by implementing research-based pedagogy and following the motto: teaching science through science.

REFERENCES CITED

- Ahlgren, A. (1996). How Standards Fit Within the Framework of Science Education Reform. In: *Issues in Science Education*. Rhoton, J. and Bowers, P. (Eds.), pp. 40-45. Arlington, VA: National Science Teachers Association.
- American Association for the Advancement of Science. (2011). *Vision and Change in Undergraduate Biology Education: A Call to Action*. Washington, DC: AAAS. Retrieved from <http://visionandchange.org/files/2013/11/aaas-VISchange-web1113.pdf>.
- Beck, C., Butler, A., & Burke da Silva, K. (2014). Promoting Inquiry-Based Teaching in Laboratory Courses: Are We Meeting the Grade? *CBE – Life Sciences Education*, 13, 444–452.
- Branschreiber, T. & Westmoreland, D. (2015). Preparing Students for Science in the Face of Social Controversy. *The American Biology Teacher*, 77 (4), 284-288.
- Cetin-Dindar, A. (2016). Student Motivation in Constructivist Teaching Environment. *Eurasia Journal of Mathematics Science and Technology Education*, 12 (2), 233-247.
- Chow, S.J., & Yong, B.C.S. (2013). Secondary school students' motivation and achievement in combined science. *US-China Education Review B*, 3 (4), 213-228.
- Crowther, D.T. (1999). Cooperating with constructivism: getting the word out on the meaning of constructivism. *Journal of College Science Teaching*, September/October, 17-23.
- Druyan, A. (Writer & Director), Soter, S. (Writer), & Braga, B. (Director). (2014). The clean room. [Television series episode] In B. Braga (Producer), *Cosmos: A Spacetime Odyssey*. Los Angeles, CA: Fox Network.
- Eastwell, P. & MacKenzie, A.H. (2009). Inquiry learning: elements of confusion and frustration. *The American Biology Teacher*, 71 (5), 263-266.
- Freeman, S., Eddy, S.L., McDonough, M., Smith, M.K., Okoroafor, N., Jordt, H., & Wenderoth, M.P. (2014). Active learning increases student performance in science, engineering, and mathematics. *PNAS*, 111 (23), 8410-8415.
- Glynn, S. M., Brickman, P., Armstrong, N., & Taasoobshirazi, G. (2011). Science Motivation Questionnaire II: Validation with science majors and nonscience majors. *Journal of Research in Science Teaching*, 48, 1159-1176.

- Hake, R.R. (2002). Relationship of Individual Student Normalized Learning Gains in Mechanics with Gender, High-School Physics, and Pretest Scores on Mathematics and Spatial Visualization. Submitted to the Physics Education Research Conference; Boise, Idaho.
- Hartle, R.T., Baviskar, S., & Smith, R. (2012). A Field Guide to Constructivism in the College Science Classroom: Four Essential Criteria and a Guide to their Usage. *Bioscene*, 38 (2), 31-35.
- Hatcher, L. & Stepanski, E.J. (1994). *A Step-by-Step Approach to Using the SAS System for Univariate and Multivariate Statistics*. Cary, NC: SAS Institute.
- Horner, Jack. (2011). *Building a dinosaur from a chicken* [Video file]. Retrieved from https://www.ted.com/talks/jack_horner_building_a_dinosaur_from_a_chicken?language=en
- Hursen, C. (2016). The impact of curriculum developed in line with authentic learning on the teacher candidates' success, attitude and self-directed learning skills. *Asia Pacific Education. Review*, 17, 73–86.
- Johnson, W. R. (2016). Why engaging in the practices of science is not enough to achieve scientific literacy. *The American Biology Teacher*, 78 (5), 370-375.
- Kahoot! (2015). www.getkahoot.com.
- Ketpichainarong, W., Panijpan, B., & Ruenwongsa, P. (2010). Enhanced learning of biotechnology students by an inquiry-based cellulase laboratory. *International Journal of Environmental and Science Education*, 5 (2), 169-187.
- Laerd Statistics. (2013). Cronbach's alpha using SPSS statistics. Retrieved May 19, 2016, from <https://statistics.laerd.com/spss-tutorials/cronbachs-alpha-using-spss-statistics.php>.
- Levitt, D., & Carroll, S. (2015). Great transitions: the origin of birds [Video file]. Retrieved from <https://www.youtube.com/watch?v=z4nuWLd2ivc>
- Liang, L.L., Chen, S., Chen, X., Kaya, O.N., Adams, A.D., Macklin, M. & Ebenezer, J. (2008). Assessing preservice elementary teachers' views on the nature of scientific knowledge: a dual-response instrument. *Asia-Pacific Forum on Science Learning and Teaching*, 9 (1): article 1.
- Lin, S. (2014). Science and non-science undergraduate students' critical thinking and argumentation performance in reading a science news report. *International Journal of Science and Mathematics Education*, 12, 1023-1046.

- Llewellyn, Douglas. (2013). *Teaching High School Science Through Inquiry and Argumentation*. Thousand Oaks, CA: Corwin
- McComas, W. F. (2015). The nature of science and the next generation of biology education. *The American Biology Teacher*, 77 (7), 485-491.
- Minner, D.D., Levy, A.J., & Century, J. (2010). Inquiry-based science instruction - what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, 47 (4), 474-496.
- Moyer, R. A. (2012). *Evaluating different levels of inquiry in the science classroom* (Unpublished Master's Project). Montana State University, Bozeman.
- National Research Council. (2012). *A Framework for K-12 Science Education*. Washington, D.C.: The National Academies Press.
- Puttick, G., Drayton, B., & Cohen, E. (2015). A study of the literature on lab-based instruction in biology. *The American Biology Teacher*, 77 (1), 12-18.
- Saunders, W. L. (1992). The constructivist perspective: Implications and teaching strategies for science. *School Science and Mathematics*, 92 (3), 136-141.
- Shell, D. F., & Soh, L. 2013. Profiles of motivated self-regulation in college computer science courses: differences in major versus required non-major courses. *Journal of Science Education and Technology*, 22 (6), 899-913.
- Schumm, M. F., & Bogner, F. X. (2016). Measuring adolescent science motivation. *International Journal of Science Education*, 38 (3), 434-449.
- Tomasik, J.H., LeCaptain, D., Murphy, S., Martin, M., Knight, R.M., Harke, M.A., Burke, R., Beck, K., & Acevedo-Polakovich, I.D. (2014). Island explorations: discovering effects of environmental research-based lab activities on analytical chemistry students. *Journal of Chemical Education*, 91, 1887-1894.
- Townsley, G. (Director). (2015). Dawn of humanity. [Television series episode] In G. Townsley (Producer), *NOVA*. Boston, MA: WGBH. Retrieved from <http://www.pbs.org/wgbh/nova/evolution/dawn-of-humanity.html>
- Unsworth, E. (2014). Macromolecules Inquiry: Transformation of a Standard Biochemistry Lab. *The American Biology Teacher*, 76 (7), 438-441.
- Wood, W.B. (2009). Innovations in teaching undergraduate biology and why we need them. *Annual Review of Cell and Developmental Biology*, 25, 93-112.

Wheeler, G.F. (2006). Strategies for Science Education Reform. *Educational Leadership*, 64, 30-34.

APPENDICES

APPENDIX A
LABORATORY INSTRUCTIONS FOR STUDENTS

1. Obtain 10 prepared test tubes for your group. One of these is a control; do not add anything further to this tube. To the three tubes marked “1.5X” add 10 mL of your wastewater sample. To three other tubes, add 0.1 mL of wastewater, and to the remaining three tubes add 1 mL of wastewater. Before you add your samples, make sure to label your tubes so you remember the dilution of each tube. Replace the caps on your test tubes once finished to help create an anaerobic environment.
2. Incubate your tubes at roughly 35⁰ C for 24 – 48 hours.
3. Observe your test tubes. Those demonstrating both yellow liquid and gas in the Durham tube are positive results. Record your data in a table that you construct.
4. You will now begin the process of inoculating Petri dishes with bacteria from only the test tubes that had a double-positive (gas plus color change) result in the presumptive test. Make sure that the dishes are properly labeled to keep track of your samples (note: it is possible to divide each Petri dish into three or four subsections to conduct multiple tests, if needed).

Flame sterilize an inoculation loop. Once cooled, dip it into the test tube to acquire a sample. Gently streak the sample onto the Petri dish. Repeat this step as necessary until all positive test tubes have been sampled and streaked. Make sure to flame sterilize and then cool your loop before obtaining each sample.

5. Place the cover on your Petri dish and store it upside down. These will now be incubated for approximately 24 hours at 35⁰ C.
6. Observe your Petri dishes. Look *for E. coli* colonies, which will turn metallic green or blue-black. If a sample contains at least one *E. coli* colony, you count that as a positive result. This means that the test tube from which the sample originated contains *E. coli*. Of the nine

experimental test tubes that you originally started with, count which were positive for *E. coli*. You will use these data and the “most probable number” table to calculate the number of bacteria in your sample. Your instructor will ask each group to share their results so that data can be collated for the entire class.

APPENDIX B

LAB MATERIALS AND INSTRUCTIONS FOR PREPARATION

Materials

•phenol red lactose broth •Levine eosin-methylene blue (EMB) agar •Petri dishes
•pipettes •test tubes •test tube caps •test tube racks •Durham tubes •safety
gloves •incubator •inoculator loops •Bunsen burner •biohazard bag •10% bleach
solution

Instructions

Nine experimental test tubes are needed per group of students, plus one control.
To reduce the amount of materials needed, four students per group is recommended.

Create the phenol red lactose broth using the easy-to-follow instructions on the package. Add 5 mL of the broth to 6 of the 9 experimental test tubes, plus the control. For the remaining three, however, you want to use 5 mL of broth that is 1.5x strength. This is done to provide enough lactose for the tubes receiving 10 mL of the wastewater sample. Label these tubes as “1.5x”. Thus, each group should have 7 tubes of normal strength broth and 3 tubes of 1.5x strength. An inverted Durham tube should also be placed in each test tube so that the open end of the tube is face down and the tube is at least halfway submerged in the broth. Then, the test tubes should be autoclaved to be sterilized before being used. The autoclave process will completely fill the Durham tubes with solution. Remove the test tubes from autoclave and cover with sterile test tube caps. These caps will later be used to create an anoxic environment for anaerobic metabolism.

Lastly, using the instructions on the package, prepare enough Levine EMB agar for three Petri dishes per group, plus a few backups. During the lab, ensure that students follow proper safety guidelines, including use of gloves when handling wastewater

samples, proper disposal or sterilization of biohazardous waste (which includes anything that has touched wastewater; consult your institution's specific safety protocols), and disinfection of lab tables using a bleach solution.

APPENDIX C

INSTITUTIONAL REVIEW BOARD APPROVAL



INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

960 Technology Blvd. Room 127
 c/o Immunology & Infectious Diseases
 Montana State University
 Bozeman, MT 59718
 Telephone: 406-994-6783
 FAX: 406-994-4303
 E-mail: cherylj@montana.edu

Chair: Mark Quinn
 406-994-5721
 mquinn@montana.edu
Administrator:
 Cheryl Johnson
 406-994-6783
 cherylj@montana.edu

MEMORANDUM

TO: Matthew Fisher and Peggy Taylor
FROM: Mark Quinn, Chair *Mark Quinn*
DATE: December 1, 2015
RE: "Immersing Students in the Process of Science to Increase Achievement, Motivation, and Attitudes Towards Science [MF120115-EX]"

The above research, described in your submission of November 30, 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 D

BIOLOGY MOTIVATION QUESTIONNAIRE II

BIOLOGY MOTIVATION QUESTIONNAIRE II (BMQ-II)

© 2011 SHAWN M. GLYNN, UNIVERSITY OF GEORGIA, USA

In order to better understand what you think and how you feel about your biology courses, please respond to each of the following statements from the perspective of “When I am in a biology course...”

Statements	Never 0	Rarely 1	Sometimes 2	Often 3	Always 4
01. The biology I learn is relevant to my life.					
02. I like to do better than other students on biology tests.					
03. Learning biology is interesting.					
04. Getting a good biology grade is important to me.					
05. I put enough effort into learning biology.					
06. I use strategies to learn biology well.					
07. Learning biology will help me get a good job.					
08. It is important that I get an "A" in biology.					
09. I am confident I will do well on biology tests.					
10. Knowing biology will give me a career advantage.					
11. I spend a lot of time learning biology.					
12. Learning biology makes my life more meaningful.					
13. Understanding biology will benefit me in my career.					
14. I am confident I will do well on biology labs and projects.					
15. I believe I can master biology knowledge and skills.					
16. I prepare well for biology tests and labs.					
17. I am curious about discoveries in biology.					
18. I believe I can earn a grade of “A” in biology.					
19. I enjoy learning biology.					
20. I think about the grade I will get in biology.					
21. I am sure I can understand biology.					
22. I study hard to learn biology.					
23. My career will involve biology.					
24. Scoring high on biology tests and labs matters to me.					
25. I will use biology problem-solving skills in my career.					

APPENDIX E
NATURE OF SCIENCE SURVEY

Survey Regarding the Nature of Science

For each one of the following statements, please choose one of the following options that best describes your viewpoint: Strongly disagree (SD), Disagree (D), neutral (N), agree (A), strongly agree (SA). Please be advised that there are no “right” answers.

Statements	SD	D	N	A	SA
1. Scientific knowledge can be modified as new and relevant evidence is collected.					
2. Scientific knowledge is not intended to be an authority on matters of spirituality and morality.					
3. If a scientist published erroneous conclusions from a study, it is likely that other scientists would identify those mistakes and seek to correct them.					
4. Scientists can only study things that are based on the physical laws of nature.					
5. Scientific knowledge is strictly based on information that can be measurable and verified.					
6. Scientists are expected to publically share their methods and conclusions so that others can scrutinize and critique their work.					
7. Scientific theories, such as the theory of evolution or the theory of plate tectonics, are developed through the accumulation of multiple lines of supporting evidence.					
8. Scientific knowledge cannot be produced without data collected through observation and/or experimentation.					
9. Science produces fact-based truths about the world.					
10. Someone cannot be both scientific and religious.					
11. Argumentation and debate are important process in the construction of scientific knowledge.					
12. There are limits to the types of questions that can be answered through science.					

APPENDIX F
INTERVIEW QUESTIONS

Interview Question

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

Questions 1-5 regard students' self-perception of motivation and interest

Opening statement: Over the last few weeks, you have participated in several lab activities that include a field trip, a lab experiment in which you tested wastewater samples, and a personalized experiment in which you tested water samples of your own choosing. From this last experiment, you presented your results to the class.

1. Please explain the ways in which any of the lab activities mentioned in the opening statement may have affected your level of interest in biology.
2. Please explain the ways in which any of the activities or content covered in the lecture portion of the class may have affected your level of interest in biology.
3. Considering only those lab activities mentioned in the opening statement, do you feel that any of them changed your opinion for how biology can be relevant to the lives of non-scientists? Please explain how participating in these activities changed your opinions, if at all.
4. Considering only the activities and content covered in lecture, do you feel that any of it changed your opinion for how biology can be relevant to the lives of non-scientists? Please explain how any elements of lecture may have changed your opinions changed, if at all.
5. Do you feel that your motivation to earn a high grade in the class has changed from the first day of class to now? If so, please discuss which specific elements of the class, whether in lecture or lab, have most strongly contributed to this change.

Questions 6-10 regard students' attitudes towards the nature of science

6. Do you feel that your understanding of how scientist go about studying the world and discovering new knowledge has changed because of this class? If so, please explain how.
7. In what ways, if any, has this class affected your ability to evaluate statements as being scientific or not? Please explain your answer.
8. In what ways, if any, do you feel that this class has changed your viewpoints towards the role of science, and biology in particular, to society?

9. Do you feel that science provides knowledge and explanations that are trustworthy? Please explain your answer.
10. Imagine a scientist that purposes a new theory, but does not provide any supporting evidence. How do you feel other scientists should react to this?

APPENDIX G
INTERVIEW TRANSCRIPTS

Transcript of Interview Responses

Interview 1. Student #8

Q1: “The fieldtrips and the water testing increased my interest in biology because it just goes to prove that even though we just drink water....Knowing that we could test it ourselves & find out things that we didn’t know about E. coli in our water...is interesting because you kinda just assume it’s safe but when you test it yourself you kinda find out that maybe it’s not”

Q2: “Well I changed my whole, um, career choice, because of...I’m going into biology now...the class just opened my eyes to like, I had a lot of questions about things, but didn’t really, I just kinda went with the flow, didn’t really think about it...you know, you wonder things, the class brought it out for me, learning so many things I didn’t know, like, holy crap, really, this is how it works?...This class helped me decide, like hey, I want to do something different, and it’s about biology...I was scared to death to take this class and now I’m glad that I did.”

Q3: “Absolutely, just like I was saying earlier, you don’t have to be a scientistgoing on these trips opened our eyes to what we didn’t know, we just go with the flow...it opens up that scientific part of your brain that you don’t think about on a daily basis, so going on these fieldtrips, yes, it is important to non-scientists because it shows you what they do, like the process taken to ensure that you’re drinking healthy water, where your water goes when it goes down the sink and down the toilet.”

Q4: “Yeah, because we don’t think about the things that scientists think about, so taking this class kind of opens up your mind to some of the things that maybe you should be thinking about. You don’t know have to be a scientist, you just have to think about these things, especially in our environment.”

Q5: “Yep, cause I mean, I always strive to try to get the best grade that I can, I always say I’m getting an A....now that I’m going into biology, like that’s what I’m pursuing as a career, it’s that much more important to get an A in the class. I’m trying harder that I was, so yah...the passions that I have in my own life, how much I care for the planet”

Q6: “Yes, because I mean when you think about scientists you think about nerdy people in lab coats and they’re sitting around in labs...they’re like total geeks, but scientists aren’t actually and they do a lot and all the things they do go into everything that we do, you don’t think about, oh a scientists did this, you think about they’re only solving the huge problems in the world, but they do everything.”

Q7: “You can’t just accept things as they are, like you should probably look into it....so, you don’t have to be a scientist, but you can’t just take everything for face value. You want to look into it and investigate it ...and I do that more now because of this class than I did at the start”

Q8: “Well, I changed my whole career path because of the class.”

Q9: “Um, yes I think that ...they’re the ones that go and put the proof out there, they’re the ones that go out and investigate things, fix things, and make things better for us...so yeah, I think they’re the ones that challenge things, they don’t just like take something at face value, they’re the ones that actually prove it. Yeah, they are trustworthy.”

Q10: “They should prove it. They shouldn’t just, you know, so if they didn’t do any research on it I would say you have to research it, as a scientists....Like if a scientist that is well known just came up and said, I think this, all the other scientists should be like, excuse me.”

Interview 2. Student #6

Q1: “I guess the thing that stood out the most was during own experiment for the wastewater samples of our choosing. Yeah, I thought that was interesting...being able to choose what we wanted to do and then control the experiment the way we wanted to do it instead of being told what to do...so I just thought that was nice and interesting.”

Q2: “I guess the Kahoot! quizzes that he did really helped my interest. It helped me understand what we were learning in that class, too. He would go over it in the lectures and stuff and go into details but I was learning better by doing these small quizzes that didn’t affect our grade at all, so I thought that was able to boost my interest in biology...and doing all of those sorts of labs I think was really nice.”

Q3: “Yeah, I thought that going on the two field trips, the wastewater and the water treatment center, because I’m from Reno, NV and we never got to do any of that stuff in any biology classes, so when I moved up here coming up and going to those facilities, seeing them firsthand how the process is done really boosted it up.”

Q4: “I guess so, I don’t know. I don’t know how to answer that one.”

Q5: “I guess the only thing that changed was the trying to get a better grade because at the beginning of the semester it was a little hard, I just didn’t really put too much effort forth, and then once I started to pay attention, like really starting to focus on the class, it started to go up, change I guess, a little bit....It was mostly the lab activities because I like doing all the, all the lab activities really helped boost that, too, because I like firsthand interaction with everything instead of just being taught out of the book or something.”

Q6: “I think it’s interesting, we learned about...a professor down in Missoula and he would go around and do look for all these samples of dinosaurs and everything, so I thought learning about that was really interesting.”

Q7: “We did an activity of learning of different statements of scientific, ah ways to spot them, in scientific ways, to explain, ah, I don’t know. I don’t really know how to answer

it. I guess the activity was one we learned, we just reviewed other peoples' statements and just evaluated the statements throughout, so I guess that really helped."

Q8: "It really didn't change my viewpoints, I mean it opened, it just expanded on some stuff that I already knew coming into the class, just expanding on those helped, too. We talked a little bit about biofuels, like I knew a little about that but having us do a debate about it really helped and I learned both the pros and cons of everything so that really helped."

Q9: "Yeah, I would say so. As long as you have the correct or proper sources to back it all up and the proper information I guess."

Q10. "They would question him I would see. Be very questionable. And I'd have to ask to see what, where his evidence came from and stuff, and see all his supporting of that."

Interview 3. Student #3.

Q1: "Well, I didn't know that biology had a lot to do with water treatment, so it was really cool seeing how it all played into it. And then when we did our own sample seeing how much *E. coli* bacteria was in the Missouri river was actually, it was gross, but it was really cool because it turned the shiny green color so I'd say that it made my interest higher than it was before, made it seem a lot cooler."

Q2: "We watched this video on human evolution, they found a bunch of fossils or bones in this cave and it was really cool to see the change in skulls and bones and just how we are built over time, so that increased by interest a lot. That was my favorite."

Q3: "Yes, so biology affects all of us with just even water, so I didn't really consider that before he introduced the whole topic. It was cool to see that even little things like that have to do with biology so it definitely applies to everyone not just biologists and scientists."

Q4: "Well, he talked about global warming and stuff, so that would definitely affect everyone not just scientists, so that would definitely affect everyone. I can't really think of anything else specifically. That one is the main one that I noticed."

Q5: "At the beginning I was like, it will be so easy to get an A because I really like biology. I took it my senior year so I thought it was really cool, and then the first test, I didn't, well he told us we'd be tested three chapters at a time, but I didn't know how difficult that would be until the first test. So much information to remember, but it didn't really decrease my motivation it just, I didn't see it being as easy as I thought it was going to be. Of course, I'm going to strive for a good grade but I just felt like it got a little harder to really set that goal to get an A."

Q6: “Yeah, I didn’t know that, how much that they still do with old, old fossils, and like bones, and then how they study so much with global warming, like I said, they just have a lot to go over. It didn’t really occur to me before how much it’s important to everything.”

Q7: “I mean, I think I could evaluate this before, too, but just seeing if something is backed up by other studies then it’s going to be more scientific than something that doesn’t have any evidence with it.”

Q8: “Well, it definitely has a way bigger impact than I thought, um, just with, I didn’t know a lot of things had to do with biology, so a lot of things that, like, I’m going to say it again, global warming, and all of that. So that affects all us and that is definitely science and biology related.”

Q9: “Yes. But only when it’s backed up. So if it’s just something that someone came up with, then not really, but definitely a lot of the things are backed up by a lot and there are proven experiments too.”

Q10: “Probably pretty wary of it, like not immediately trusting it but maybe also not throwing it out the window, maybe coming up with a possible experiment to maybe test that.”

Interview 4. Student #9

Q1: “I think in some ways it raised my level of interest in biology, especially when we went to the wastewater treatment because it kind of showed a different side that I hadn’t been previously exposed to.”

Q2: “What I found most interesting were the sections on human genetics and human evolution. Those are kind of areas that I’ve always been interested in. And that’s about the only part of biology that really like blows my mind. So I’ve always wanted kinda like do more continued research in that, but I’m not going into a biology field, it’s kind of a wash in some ways.”

Q3: “It definitely opened my eyes, a little more I think. When you’re not going into a science specific field or something that is going to deal with science heavily later on in a career you go a little bit blind to ways the science is used in everyday life, like the wastewater treatment for example. I don’t think many people know what goes on there until you actually gone there and explored it.”

Q4: “I definitely feel it did, again kind of going back to human genetics and evolution, that’s something that obviously affects all of us. So being able to understand that a little bit more and then be able to explain it to other people that have questions on it who didn’t major in science or do scientific things, it’s kind of important because it helps me engage someone else that hasn’t thought about science previously either.”

Q5: "I don't think that my motivation has really changed, I have always wanted to be a high grade earner, sometimes that doesn't happen like you do bad on a test because you didn't study well enough or something like that, but my motivation from day one is still the same, I still want to have high grades, I still want to do well so when I go to UGF my tuition is knocked down because of higher grades."

Q6: "I feel that I have a bit more information behind it, um, what we go through in the high school courses doesn't go as in-depth into scientific knowledge and discovery. It gives you an overview to kind of get the gist of what you're going to be doing when you make your own hypothesis and design your own labs or go through labs, but it doesn't really help you understand why things are the way they are for scientists."

Q7: "I think it gave me a little more clarity on it, um, we definitely all know the difference between like a scientific journal and a tabloid, so when you see something like, aliens visit president Obama on a tabloid you obviously know that's not true because it's not coming from a scientific journal. Now if it came from science news weekly or something like that, I'd probably be apt to read it, but it just those tabloids you should obviously know that it's not."

Q8: "I'm not really sure, I mean it's definitely opened my eyes a little bit more to how in-depth science goes and scientific knowledge and studies and all that. And I think if more people like read more scientific journals or things like that they'd have a better understanding about science stuff. But I think society likes to try to be blind to it because it doesn't fit the norms or what we expect."

Q9: "I do, because they have to go through really in-depth research, they have to put their answers out there and people critique them like crazy, so that kind of makes a person more apt to like slow down and really think about what they're going to put out there and be like, people are going to critique this, how will I take that criticism? So I think that it becomes more trustworthy because more people are looking at, hey maybe you're wrong here why don't we go research that a little bit more, or, I agree with you and here is a little bit more research that we can pony up and do together."

Q10: "I feel like they should just definitely like jump on it and um, go more in-depth to it, like why wasn't there any research backed up to this, are these claims factual or are they kind of just like some misconstrued idea and that's why they didn't put facts up, or if there are reasons for no facts, and then if they can find facts or any supporting evidence they should publish those and get those out there so that the scientific world and society in general has a better understanding of what was just mentioned."

Interview 5. Student #1.

Q1: "I'm gonna say going on the fieldtrips. It was a really good experience to go on the fieldtrips and get a more hands-on learning than just sitting in a classroom reading from a book."

Q2: "I guess, you know, going through the books and having a reading quiz every few weeks was pretty, you know, nice. So obviously we're learning a lot of stuff, it was nice to know that."

Q3: "Going on the fieldtrips kind of showed us non-biology people how the waste treatment and the water treatment, you know, treat our sewers and waters, and how we get our water treated. So, it was interesting."

Q4: "Learning all of the subjects of biology and knowing what they do and how they affect the non-biologists."

Q5: "Well, since the beginning I was always interested in having a higher grade, and seeing that I'm still getting a higher grade, it kind of helps keep me getting that higher grade."

Q6: "Yes, it's nice to know, you know, that scientists are still discovering things like the human evolution and they're finding new human evolution stuff."

Q7: "I guess the last assignment we had, you know, is this true or not, give the reasons and statements for why this is true kind of showed that how it can be scientific or not."

Q8: "I don't know, um. It's nice to know that it affects everybody, and understanding of how it affects everybody, so having a great understanding of how science is even relevant to life right now."

Q9: "Um, yes, if they provide, you know, the right materials of how they got it, if you can reproduce the experiments yourself and the different variations of the experiments, I feel like it could be trustworthy."

Q10: "Well, I feel like that the other scientist should get in contact with that scientists and find out what else happened, you know, why didn't you have any supporting evidence, can we try this and find some supporting evidence, is what I feel like they should do."

APPENDIX H
CONTENT ASSESSMENT

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

Please answer these questions to the best of your ability. Record your answers for questions 1 -18 on a Scantron form. Please put your name on it. This quiz is NOT graded. If you don't know the answer, do NOT guess. Instead, please pick option E.

1) An organism gets its energy from the sun and its carbon from organic molecules. Therefore, this organism is a...

- A. photoautotroph.
- B. photoheterotroph.
- C. chemoautotroph.
- D. chemoheterotroph.
- E. I don't know

2) Which one of the following best describes the term "bioremediation"?

- A. Transferring genes from one organism to another
- B. Using organisms to remove pollutants
- C. Inducing mutations to create new species
- D. Utilizing living things to create commercially valuable products
- E. I don't know

3) The element nitrogen is important to all living things because it is...

- A. found in nucleic acids and proteins.
- B. found in proteins and lipids.
- C. found in nucleic acids and carbohydrates.
- D. a component of N_2 .
- E. I don't know

4) What is the purpose of primary wastewater treatment?

- a) remove suspended solids.
- b) remove dissolved organic material.
- c) remove excess nitrogen.
- d) disinfect the water.
- e) I don't know.

5) In the multiple tube fermentation technique, what causes phenol red to change yellow?

- A) increased urea concentration
- B) acid production by bacteria
- C) lactose production by bacteria
- D) an increase in dissolved solids
- E) I don't know.

- 6) In the multiple tube fermentation technique, what causes gas to accumulate in the Durham tubes?
- A) the activity of bacteria
 - B) the reaction of different inorganic compounds
 - C) air being drawn in from the outside environment
 - D) photosynthesis
 - E) I don't know.
- 7) Which of the following water sources would you expect to have the lowest amount of bacteria?
- A. outfall
 - B. primary clarifier
 - C. secondary clarifier
 - D. tertiary treatment bioreactor
 - E. I don't know
- 8) _____ convert usable nitrogen (which can be used by plants) into N_2 , which is unusable.
- A) Nitrifying bacteria
 - B) Nitrogen-fixing bacteria
 - C) Denitrifying bacteria
 - D) Fungi
 - E) I don't know
- 9) An organism that extracts energy from chemicals and carbon from organic molecules is a...
- A) photochemotroph.
 - B) photoheterotroph.
 - C) chemoheterotroph.
 - D) chemophototroph.
 - E) I don't know.
- 10) What is the purpose of secondary wastewater treatment?
- A) remove bacteria.
 - B) remove dissolved organic material.
 - C) remove suspended solids.
 - D) remove excess nitrogen.
 - E) I don't know.

- 11) In an experiment testing the effects of a drug on weight loss, which one of the following would best represent a hypothesis?
- A. the drug will cause people to lose weight because it increases their metabolism
 - B. people that take the drug will lose weight
 - C. 20 people will be given the drug
 - D. A control is needed to make accurate conclusions
 - E. I don't know.
- 12) Which one of the following processes would specifically target the removal of nitrogen from wastewater?
- A. primary treatment
 - B. secondary treatment
 - C. tertiary treatment
 - D. quaternary treatment
 - E. I don't know
- 13) Which of the following processes rely on bioremediation?
- A. primary treatment
 - B. secondary treatment
 - C. tertiary treatment
 - D. B and C
 - E. I don't know
- 14) Which of the following processes involve bioremediation?
- A. wastewater treatment
 - B. drinking water treatment
 - C. distilled water processing
 - D. all of the above
 - E. both I don't know
- 15) Nitrogen fixation is a process that results in....
- A. N_2 being converted into NH_3
 - B. NH_3 converted into N_2
 - C. NO_3^- being converted into NO_2^-
 - D. N being converted into C
 - E. I don't know
- 16) During one particular step of wastewater treatment, fine organic material is removed at the molecular level. What happens to it?
- A. It is removed as a gas
 - B. It is filtered out
 - C. The matter is completely annihilated
 - D. It is radiated outward as excess heat
 - E. I don't know

17) What is the purpose of the aeration basins at the Great Falls Wastewater treatment plant?

- A. To prevent blockage of drainage pipes by sludge
- B. To provide gases needed for microbial metabolism
- C. To blow out solid waste material
- D. To increase the flow rate of the sewage
- E. I don't know

18) What removes dissolved organic material and nitrogen from the wastewater treated at the Great Falls plant?

- A. microbes
- B. filters
- C. animals
- D. machines
- E. I don't know

For questions 19 – 20, if you don't know the answer please do NOT guess. Instead, leave the area blank.

19. What is the specific environmental source of the drinking water used by the City of Great Falls?

20. After treatment, wastewater that originally came from sources like showers, sinks, and toilets is discharged into what specific feature?

APPENDIX I

SUMMARY OF RESPONSES FROM POST-INTERVENTION INTERVIEWS

Question	Summary of Response, with selected quotes
1: Which lab activities influenced your level of interest in biology?	Four students identified the fields, while the water quality inquiry-based labs were mentioned by three students. “I didn’t know that biology had a lot to do with water treatment, so it was really cool seeing how it all played into it. And then when we did our own sample seeing how much <i>E. coli</i> bacteria was in the Missouri River was actually, it was gross, but it was really cool” – Student #3 “...being able to choose what we wanted to do [in the inquiry lab] and then control the experiment the way we wanted to do it instead of being told what to do.” – Student #6
2: Which lecture activities influenced your level of interest in biology?	No common theme emerged here. The responses ranged from quizzes to a video on evolution shown in class. One person mentioned that the class made her change careers from education to biology. “I changed my whole, um, career choice, because of, I’m going into biology now...the class just opened my eyes” – Student #8 “I guess the Kahoot! quizzes that he did really helped my interest. It helped me understand what we were learning in that class, too.” – Student #6
3: How have labs changed views of biology’s relevance?	Four of five students indicated that lab activities changed their views. The fifth student’s answer was vague in this regard. All five students directly mentioned or alluded to the field trips. “Going on the fieldtrips kind of showed us non-biology people how the waste treatment and the water treatment, you know, treat our sewers and waters, and how we get our water treated. So, it was interesting.” – Student #1 “[the fieldtrip are] important to non-scientists because it shows you what they do, like the process taken to ensure that you’re drinking healthy water, where your water goes when it goes down the sink and down the toilet. –Student # 8
4: How has lecture changed views of biology’s relevance?	Two students said their views towards this have increased, but did not give any specific details regarding how class contributed to this. One student was not able to give a response. The remaining two students had this to say: “he talked about global warming and stuff, so that would definitely affect everyone not just scientists, so that would definitely affect everyone.” – Student #3 “I definitely feel it did, again kind of going back to human genetics and evolution, that’s something that obviously affects all of us. –Student #9
5: What caused levels of motivation to change?	Four students said motivation come from within or simply the desire to get a good grade. One student attributed his change to lab activities. “I don’t think that my motivation has really changed, I have always wanted to be a high grade earner.” – Student #9 “It was mostly the lab activities because I like doing all the, all the lab activities really helped boost that, too, because I like firsthand interaction“– Student #6

6: Has class changed your views regarding how scientific knowledge is produced?	All five students stated that the class increased the perception of how scientific information is produced. Two, however, did not directly address how the class specifically contributed to this. Two made reference to a video on an important discovery in paleoanthropology, one made reference to a Ted Talk by paleontologist Jack Horner. One of these students also referenced the class discussion on how evidence of global warming is produced. “I didn’t know that, how much that they still do with old, old fossils, and like bones, and then how they study so much with global warming” – Student #3 “I feel that I have a bit more information behind it, um, what we go through in the high school courses doesn’t go as in-depth into scientific knowledge and discovery” – Student #9
7: Has class changed your ability to discern scientific statements?	All five students felt that the course increased this ability, however three students gave vague answers that didn’t specify which part of class contributed. The other two students mentioned the in-class activity on classifying statements as scientific or not. “you don’t have to be a scientist, but you can’t just take everything for face value. You want to look into it and investigate it ...and I do that more now because of this class than I did at the start” –Student #8 “the last assignment we had, you know, is this true or not, give the reasons and statements for why this is true, kind of showed how it can be scientific or not.” - Student #1
8: Has class changed your views regarding role of biology in society?	All five students indicated that the course positively increased this perception. Three students provided non-specific responses. The other two students are summarized here: “We talked a little bit about biofuels, like I knew a little about that but having us do a debate about it really helped and I learned both the pros and cons of everything so that really helped.” – Student #6 “it definitely has a way bigger impact than I thought...I didn’t know a lot of things had to do with biology, so a lot of things that, like, I’m going to say it again, global warming, and all of that.” – Student #3
9: Is scientific knowledge trustworthy?	All five students indicated in the affirmative. In their explanation, all students mentioned that it is trustworthy because there is evidence and research behind that knowledge. “Yes, I think that they’re the ones that go and put the proof out there, they’re the ones that go out and investigate things, fix things, and make things better for us” – Student #8 “I do, because they have to go through really in-depth research, they have to put their answers out there and people critique them like crazy, so that kind of makes a person more apt to like slow down and really think about what they’re going to put out there” – Student #9
10: How should scientists react to new theory that lacks supporting evidence?	All five students indicated that scientists should react with skepticism and require some sort of corroborating proof. “They would question him I would see. Be very questionable. And I’d have to ask to see what, where his evidence came from and stuff, and see all his supporting of that.” – Student 6 “I feel like they should...go more in-depth to it, like why wasn’t there any research backed up to this, are these claims factual or are they kind of just like some misconstrued idea and that’s why they didn’t put facts up?” – Student #9