GUIDED INQUIRY LABS IN AP PHYSICS

by

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DEDICATION

This project and paper are dedicated to my loving wife, Andee, who has taken on far more than her fair share to allow me to pursue this degree.

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ABSTRACT

This study was performed to determine the impact of guided inquiry experiments on students in AP Physics C: Mechanics. Qualitative and quantitative data were gathered to answer the following questions: What are the effects of introducing guided inquiry experiments on student enjoyment of physics? The following secondary questions were also investigated: Does conducting guided inquiry experiments improve student retention of course material? Does conducting guided inquiry experiments improve students' ability to write about science? Two sections were used as a treatment and non-treatment group. As one group conducted guided inquiry experiments, the other performed traditional experiments. After the first round of treatment, the groups were swapped. Surveys and interviews were conducted before, during, and after both rounds of treatment.

Results of the study indicated that students who received the treatment early in the year enjoyed guided inquiry more and became more comfortable with independence than the group who received the treatment in the second semester. Results showed no significant impact on retention of course material or science writing ability. It is hypothesized that those students who formed good experimental habits by performing inquiry early in the year were better able to adapt and enjoy the experiments than those who started out in the non-treatment group performing traditional experiments.

INTRODUCTION AND BACKGROUND

As a science student, most of my experience performing labs and experiments consisted of being handed a set of instructions, sitting in front of a pre-set apparatus, and being told what I was supposed to find. It was not until late in my college career that I was given the opportunity and freedom to design my own experiment without the framework of instructions or predetermined goals. Only then did I realize how much troubleshooting, problem solving, planning and improvisation is involved in carrying out an investigation. The importance of understanding the problem at hand, utilizing the underlying physical laws, and executing a well-planned experiment can be completely lost on students when none of the responsibility for doing those things falls on them. Experiencing the challenging uncertainty and eventual satisfaction of success of solving a real-world problem enriched my science education directly, but it also lent valuable perspective to all the pen-and-paper example problems I had been given to work through.

As a science teacher, I have come to understand the value of experiments not only as a vital part of instruction, but also a dimension that generates enjoyment among students. Simply put, labs are fun! Having executed countless “cookbook” experiments in my own education, I can see that the effect on students is similar to what I experienced. For many, there is little thought put into the reason for the tests being done and rarely do students truly and deeply understand how the underlying physical principles determine the result. The net effect is that few students garner knowledge and most carry forward little or no improved understanding. As teachers we hope the experiments enrich and deepen students learning, however many simple experiments fail to do this.

I teach physics and physics honors at Blair Academy, a private boarding school in Blairstown, New Jersey. The school has a current total enrollment of 460 students, including approximately 80 day students. Blair is a very student-centered learning environment with a student to faculty ratio of 6:1, an average class size of 12, and includes international students from 28 different countries. While private schools are sometimes thought to be populated only by the wealthy, Blair awards a total of $6.6 million in scholarships annually, resulting in a socioeconomically diverse student body. The school offers 175 courses, 52 of which are at the honors and AP level. (Blair @ a Glance, 2017). Students at Blair are required to take three years of lab sciences, generally including biology, chemistry, and physics, however there are several science electives available such as astronomy, marine biology, environmental science, and robotics. Physics is offered as a course for students in their junior year and involves a significant amount of geometry and algebra, as opposed to a more conceptual approach that would involve less math. As one might expect, the math content is more rigorous for students at the honors level.

For the first few years of my teaching career I planned and carried out many traditional labs. I wrote instructions, set up several copies of the same apparatus, and worked out exactly what result students should expect. I gave little consideration to changing my practices until I began to observe students repeatedly gleaning little or no benefit from the experiments. There was no external pressure to change things, in part because Blair Academy does not follow or employ any specific teaching standard, and the most recent pedagogical developments often go unexamined. As an independent school, the Blair and its administration have the ability to allow faculty the autonomy and creative freedom to develop their class curriculum as they see fit. This is a significant advantage of working at an independent school and has allowed me to do things like develop an astronomy course from scratch. However, the lack of impetus to improve my practices caused me to stagnate in my teaching, falling into the same trends I experienced as a student.

Students at Blair are generally highly motivated and aspire to attend top colleges and universities in the United States and abroad. Many have become accustomed to following instructions fastidiously so as to meet all expectations of their teachers and earn the highest possible grade. As such, my attempts at conducting labs without specific instructions are often met with some confusion and anxiety. Students hesitate, waver, and often fail to act for an entire fifty-minute class meeting, paralyzed by their unfamiliarity with independent endeavors. However, once the initial uncertainty is overcome, students' curiosity and creativity can take over and the hope is that they will more clearly see how to apply what they have learned from the preceding lessons.

Inquiry based learning changes the focus of science instruction. In general, the various levels of inquiry take the onus off the teacher and place more responsibility with the student to identify problems, ask questions, plan investigations, and develop solutions. Guided inquiry exists somewhere in the middle of the inquiry spectrum and involves a balance between student independence and instructor direction.

Employing guided inquiry is my attempt to remedy many of the problems in my own teaching. I have seen how little students sometimes learn from traditional labs, and I want to improve on that. Additionally, I want my students to be challenged by experiments in such a way that they feel they have actually accomplished or discovered something in finding their answer. As promising as guided inquiry is, however, it is important, to methodically and diligently examine its effects on my teaching, students' retention, and their ability to write about science as the practice is implemented.

My experiences as a high school and undergraduate student, followed by a number of years as a science teacher led me to develop my primary research question: what are the effects of introducing guided inquiry experiments on student enjoyment of physics? In addition, the following secondary questions will be researched.

1. Does conducting guided inquiry experiments improve student retention of course material?
2. Does conducting guided inquiry experiments improve students' ability to write about science?

CONCEPTUAL FRAMEWORK

The effectiveness of non-traditional teaching methods has been debated since J. S. Bruner (1961) argued for an emphasis on problem solving as the basis for learning science. Bruner asserted that discovery was the best method for developing understanding and that expository teaching methods are less effective. Structuring a science course around the process of independent inquiry has become a favored practice among many science teachers, and it is often thought to lead to a richer experience for students. Inquiry learning shifts the focus of the classroom away from a teacher presenting facts and explaining concepts, to students who pose questions and investigate answers on their own. It is a multi-faceted approach to teaching science that focuses on three main pillars. Llewellyn (2013) discusses these in detail, noting that they include the ability to do scientific process, knowledge about the process, and the practice of teaching students science content alongside the methods used by actual scientists.

Removing the teacher from the center of the classroom and placing the onus on students constitutes a significant shift in educational philosophy. In recent decades there has been a concerted effort to determine exactly how this kind of inquiry-based learning can and should be incorporated into the science classroom in order to maximize student performance and understanding. There was a steady and significant increase in the number of publications on the role of the teacher in the science classroom from 2003-2012, with the vast majority of those conducted in North America and Europe (Dobber, Zwart, Tanis, & van Oers, 2017). One assessment of research on teaching strategies in science that surveyed a number of separate studies concluded that student-centered pedagogies such as project-based learning, peer-led team learning, and process oriented guided inquiry learning (POGIL) improve student outcomes. In particular, the POGIL approach showed clear benefits in not only academic achievement, but in overall student engagement as well as student and teacher enjoyment (Eberlein, et al. 2007). Another study focused on students at the undergraduate level at two separate institutions found that students demonstrated significantly improved confidence in science and scientific reasoning skills (Beck & Blumer, 2012). As a result, inquiry-based learning has been generally accepted as an effective method for improving student understanding of science content and scientific practices. In fact, most state and national science standards incorporate some aspect of inquiry, including the National Science Education Standards which emphasize inquiry because of its similarity to scientific practices and its ability encourage the development of scientific understanding and knowledge (Banerjee, 2010).

However, some experts refute the effectiveness of independent discovery as a learning technique and say that its methods are contrary to our understanding of cognition and how new memories are formed (Kirschner, Sweller & Clark, 2006). Learning can be defined as the formation of new long-term memories. Some thorough reviews of research indicate no significant improvement in long term memory formation has been demonstrated when using open inquiry style instruction. It is argued that experiential learning is only effective when students have a base of knowledge from which to work, and that base must be built through traditional instructional practices. However, for students with some prior knowledge, learning outcomes are roughly equivalent when comparing traditional and inquiry instruction. Thus, there seems to be no significant disadvantage to inquiry either (Kirschner et al., 2006). What is ignored in this analysis, however, is the effect of inquiry on student engagement and enjoyment, as well as the effect of inquiry practices that involve more guidance from the instructor.

It is also argued that the benefits of inquiry learning extend beyond remembering new information. Independent investigations develop the habits of mind required to do science, including higher-order thinking skills, problem-solving skills, and critical and scientific reasoning (Llewellyn, 2013). The abilities honed by learning through inquiry, such as forming questions, designing investigations, and gathering and analyzing information, are the tools that make one a lifelong learner (Llewellyn, 2013).

Other concerns have been expressed about inquiry-based learning, including the productivity of the class and the safety of students and teachers in the laboratory. While the benefits of independent discovery can be significant, one can easily imagine that giving students free reign over materials and equipment in a chemistry lab, for example, could quickly lead to disaster. Additionally, many teachers are concerned that the open-ended nature of inquiry activities may result in reduced coverage of required curricular material, particularly when under the pressure of standardized testing (Tan & Caleon, 2016). Despite perceived drawbacks, many assert that, in general, inquiry style instruction does produce a measurable, positive impact on students. Teachers must pay close attention to the student’s role as well as their own, and to the methods by which they attempt to measure the result of their efforts (Anderson, 2002).

The traditional model of experimentation in the science classroom is sometimes referred to as confirmation inquiry. In confirmation inquiry, each student activity has a specific desired result for which students are given equipment and procedures, and are told what result they should expect (Arslan, 2014). There are essentially three other approaches that science educators may use for inquiry-based experiments. They are structured inquiry, guided inquiry, and student-initiated inquiry. Structured inquiry involves students following procedures identified by the teacher and interpreting data to answer specific questions but are not told what result they are to find. At the other end of the spectrum is student-initiated inquiry, in which students take complete ownership over the experimental process, identifying questions, choosing and designing methods of investigation, data collection, and analysis, with minimal teacher input (Llewellyn, 2013).

Some studies have shown that only students who are accustomed to open inquiry might be able to thrive in such an unstructured environment. A student who has only ever experienced confirmation inquiry labs will be unprepared or unable to independently derive questions, hypotheses, and methods of data gathering (Arslan, 2014). Guided inquiry serves as a middle-ground, striking a balance between instructor input and student freedom. Broadly speaking, students are free to design their own experiment to address a question posed by the teacher and are gently guided by the instructor to stay on the right course (Tan & Caleon, 2016). Guided inquiry represents a flexible compromise between allowing students to explore natural phenomena for themselves and providing a structured environment in which teachers can assure student progress and safety. Guided inquiry, therefore, may serve as a useful transition for students and teachers who are new to inquiry-based activities, and can provide many of the same learning benefits as open inquiry (Arslan, 2014).

METHODOLOGY

The study includes two sections of Advanced Placement (AP) Physics C: Mechanics, including 12 male students and 10 female students (*N*=22). Students' grade levels range from tenth grade to twelfth grade and the study population includes 11 international students. The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained (Appendix A).

In order to determine the effect of guided inquiry experiments on enjoyment and engagement of physics two sections of AP Physics were separated into a treatment and a non-treatment group. The non-treatment group performed three traditional classroom experiments using a prescribed procedure and apparatus. The design of the experiment and the methods used to collect and analyze data were decided by the instructor and given to the students in the form of a lab handout. The treatment group performed three guided inquiry experiments in place of the traditional ones. The guided inquiry experiments were designed to parallel the traditional experiments performed by the non-treatment group. They involved the same concepts and shared the same goal; however, students in the treatment group were only given a prompt in the form of a question written on the board. They were then required to use their knowledge of physics concepts and the equipment in the laboratory to design and conduct an experiment that could answer the question posed. After the first round of treatment, the groups were swapped so that both sections were exposed to the treatment separately. Each of the two rounds of treatment spanned one unit of curricular content. All data collection tools were administered to both treatment and non-treatment groups throughout.

Data collection was conducted to answer the primary focus question as well as two sub-questions. Several different data collection instruments were utilized before, during, and after treatment. The focus questions and the instruments used in an attempt to answer each one are shown in the data triangulation matrix (Table 1).

Table 1
Data Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
Primary Question: 1. What are the effects of introducing guided inquiry experiments on student enjoyment of physics?	Pre- Mid- and Post-Treatment Surveys	Pre- Mid- and Post-Treatment Interviews	Instructor observations and journaling
Sub-Questions: 2. Does conducting guided inquiry experiments improve student retention of course material?	Compare scores on unit tests between treatment and non-treatment groups	Compare scores on quizzes between treatment and non-treatment groups	Instructor observations and journaling
3. Does conducting guided inquiry experiments improve students' ability to write about science?	Compare lab report grades between treatment and non-treatment group	Pre- Mid- and Post-Treatment Survey Responses	Instructor observations and journaling

Prior to treatment both groups were given the Ryerson Pre-Treatment Survey to establish students' attitudes and prior experiences in regard to classroom experiments in science (Appendix B). This survey, along with all others used in this study, were written and derived based the instructor's own experience, and what the instructor believed would elicit meaningful data. The Ryerson Pre-Treatment Survey consisted of Likert-style questions focused on each subject's perception of themselves as a science student, whether they are comfortable during experiments in which they do not know exactly what to do next, what they feel they get out of doing experiments, and how much pride and ownership they feel in their work. Other multiple-choice questions were intended to determine what type of science classes and experiments students have experienced in the past, specifically whether they have experienced some degree of inquiry instruction before. Lastly, the survey includes open-ended questions that ask students to recount their ideal experimental experience. To analyze the results, Likert responses were given ordinal values with 1 representing strongly disagree, 2 representing disagree, 3 representing agree, and 4 representing strongly agree. For some questions 1 represented Never, 2 represented Rarely, 3 represented Sometimes, 4 represented Often, and 5 represented Always. Means and medians were calculated for each Likert-style question and compared to responses to corresponding questions on later surveys.

Alongside the Ryerson Pre-Treatment Survey, Pre-Treatment Interviews were conducted to collect more information on student attitudes (Appendix C). Questions were similar to those contained in the Ryerson Pre-Treatment Survey, but they were asked in person to elicit more thoughtful responses. Responses were carefully analyzed for trends and used to support conclusions drawn from other data collection tools.

During treatment, the Ryerson Mid-Treatment Survey was administered to determine how the experiments were affecting the experience of students in class (Appendix D). Student responses were collected while they were tackling guided inquiry experiments. As such, the Likert-style questions focused on their attitudes and feelings about the labs being completed at the moment. Some of the questions paralleled questions from the Ryerson Pre-Treatment Survey, including those concerning whether they are comfortable during experiments when they do not know exactly what to do next, what they feel they get out of doing experiments, and how much pride and ownership they feel in their work. The Ryerson Mid-Treatment Survey also included open-ended questions asking what, if anything, students would change about how we are doing labs. Responses were examined for general trends. Additionally, for those questions with corresponding versions in the Ryerson Pre-Treatment Survey, responses were analyzed using a

Randomization Permutation Test. For all Randomization Permutation Tests, a p-value was calculated. The p-value can give an indication of whether two groups of numbers are significantly different. Generally speaking, a p-value of 0.05 or lower indicates a 95% confidence level that the groups are different. This was the threshold for significance throughout the analysis. The Ryerson Post-Treatment Survey is very similar in format and content to the Ryerson Mid-Treatment Survey and was administered and analyzed in a similar manner (Appendix E).

Interviews were also conducted during and after treatment to gather more qualitative data on student experiences (Appendices F & G). The questions parallel those in the Ryerson Mid-Treatment Survey and the Ryerson Post-Treatment Survey respectively and were used in an attempt to gain more depth and detail in students' responses. Responses were once again analyzed for trends and used to support conclusions drawn from other data collection tools.

Each experiment was accompanied by a laboratory report. These reports were submitted by students a few days after completing the experiment and included an introduction, methods, results, and discussion sections. They were graded on thoroughness and clarity of presentation, analysis of data, and arguments made for validity or invalidity of any conclusions they drew. The progress of students' writing ability was tracked based on lab report grades and on qualitative observations noted in the instructor's journal. Notes included specifics strengths and weaknesses of various students. This qualitative data was examined for trends and differences between treatment and non-treatment groups. Lab report grades were compared in two ways. First the grades of the treatment and non-treatment group were compared using a Randomization Permutation Test.

During each round of treatment, a quiz was taken by students. Furthermore, as each unit came to an end, a summative assessment was administered. These assessments followed the format of the AP exam and included both multiple-choice questions and free response problems. Grades on all assignments at Blair Academy are given on a scale of 1.0 – 6.0 in increments of 0.5. The Blair Academy Student Handbook (2019) details the meaning of each grade level (Table 2). While there is some subjectivity to the assignment of grades in this system, all reasonable attempts were made to standardize the grades earned by each student.

Table 2
Blair Academy Grading Scale and Explanations of Each Grade Level

Grade	A suggested list of descriptors is shown below. No weighting is used
6.0	Truly exceptional (beyond A+)
5.0/5.5	Excellent (A/A+)
4.0/4.5	Good to very good (B-/B/B+)
3.0/3.5	Acceptable (C/C+/B-)
2.0/2.5	Passing (D/D+)
1.0	Failure (F)
1.0	Work not submitted

The results were compared between the treatment and non-treatment groups to determine if the treatment had improved students’ understanding of the course content. This assessment was not designed any differently because of the treatment and was identical for both treatment and non-treatment groups. Scores were calculated according to Blair Academy’s grading standards and results were compared using a Randomization Permutation Test.

DATA AND ANALYSIS

The results of the Ryerson Pre-Treatment Survey showed that prior to this study only 14% of students (*N*=22) had experienced open or guided inquiry experiments. While 27% of students indicated they had always been given specific step-by-step instructions for experiments, 59% said that they had been expected to prove or disprove a specific idea using general guidelines. In a related question, 68% of students indicated they Agree and 18% Strongly Agree that they feel uncomfortable when they do not know what to do next during an experiment (Figure 1). Responses from the treatment and non-treatment groups were nearly identical for this question.

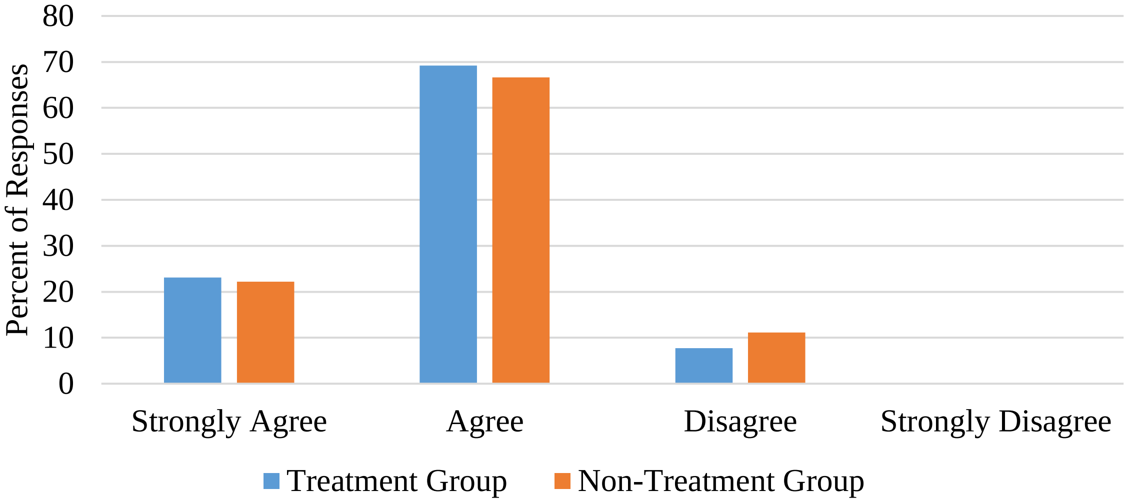

Figure 1. Ryerson pre-treatment survey (round 1) question: “Generally speaking, I am uncomfortable when I do not know what to do next in an experiment,” (*N*=22).

In the follow-up interview one student said, “I would worry that I messed something up, and would only realize when it’s too late while writing my report, and then I’ll get a bad grade.” Many students shared a similar sentiment. The instructor’s observations during the first experiment record instances of haphazard planning, poor experimental design and lack of foresight in the treatment group. Students in the treatment group were given a second class period to complete the experiment. On the other hand, the non-treatment group completed the experiment in one class period with 15 minutes to spare.

At the start of the second round of treatment, the Ryerson Pre-Treatment Survey indicated that the members of the new non-treatment group (the students who had just finished the treatment period) were more comfortable when they did not know what to do next than the students in the new treatment group (Figure 2). The mean response from the non-treatment group was 0.66 higher than that of the treatment group, and a randomization test gave a value of >0.001. As the second round of treatment began, a student in the non-treatment group, upon entering class and finding instructions waiting for her, exclaimed “aw man, instructions? This is boring.” There was some agreement from her peers.

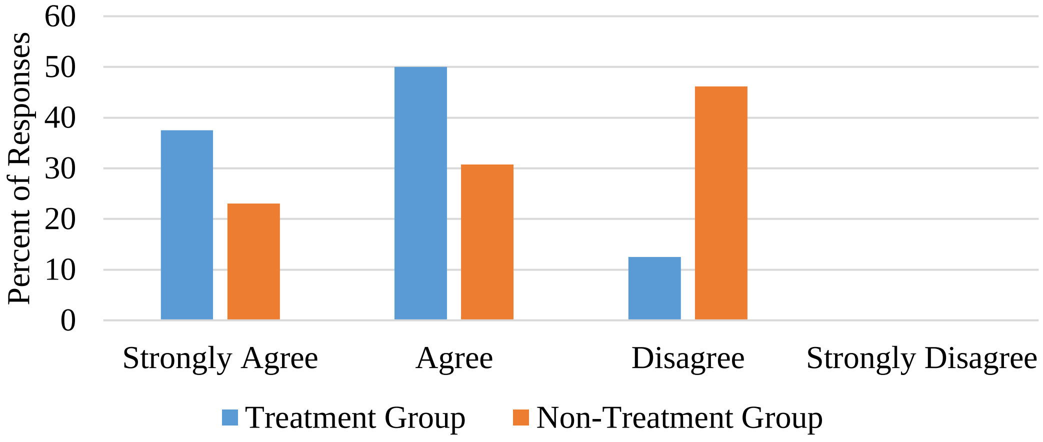

Figure 2. Ryerson pre-treatment survey (round 2) question: “Generally speaking, I am uncomfortable when I do not know what to do next in experiments,” (*N=22*).

Analysis of the Ryerson Mid-Treatment Survey during the first round of treatment revealed the same trend (Figure 3). When asked to respond to the prompt “I feel more comfortable than I used to when I don’t have instructions on what to do next,” the treatment group's mean response was 0.64 higher than that of the non-treatment group, and a randomization permutation test yielded a p-value of 0.074.

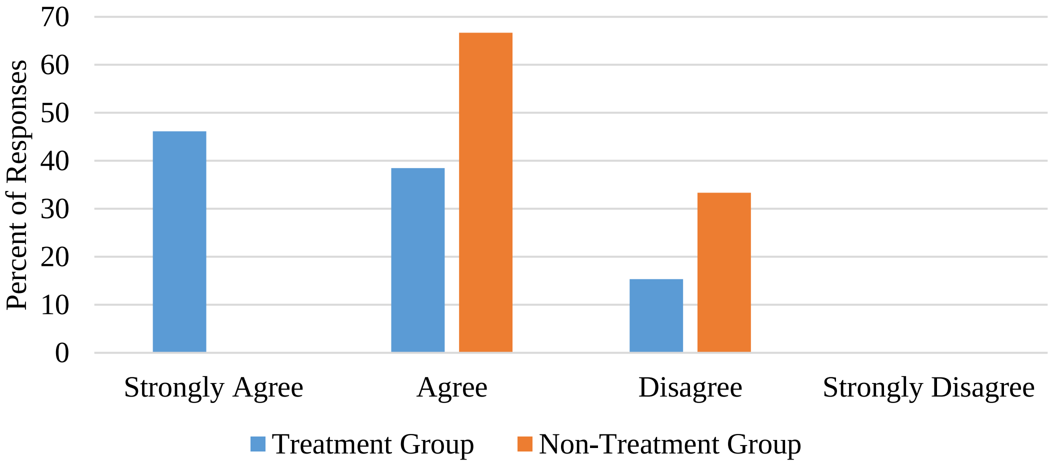

Figure 3. Ryerson mid-treatment survey (round 1) question: "I feel more comfortable than I used to be when I don't have instructions on what to do next," (*N*=22).

Instructor's recorded observations indicate a similar shift in ability to design and execute an experiment. During the second experiment, students in the treatment group moved more deliberately and confidently around the lab, putting more thought into the design process before they started recording data. Once again, the non-treatment group completed the experiment easily within the time restraints of one class period.

The Ryerson Post-Treatment Survey contains the same question, and when administered at the end of the first round of treatment, the responses changed slightly (Figure 4). While the mean response of the treatment group increased by 0.07, the mean responses from the non-treatment group increased by 0.51, bringing the difference to 0.16. A randomization permutation test gave a p-value of 0.40.

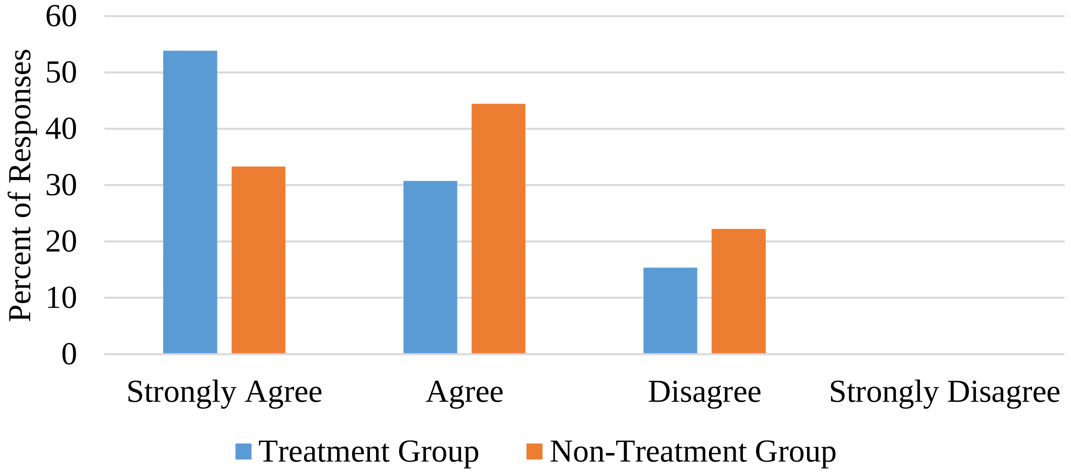

Figure 4. Ryerson post-treatment survey (round 1) question: “I am more comfortable than I used to be when I don’t have instructions on what to do next,” (*N*=22).

During the second round of treatment, mean responses on the Ryerson Mid-Treatment Survey as to whether students felt more comfortable than they used to when they don’t have instructions indicated that the non-treatment group was actually more comfortable (Figure 5). The mean response from the treatment group was 0.45 lower than the mean response from the non-treatment group, however a randomization test yielded a p-value of 0.229. The same question on the Ryerson-Post Treatment Survey indicated no difference between the two groups, as the mean response from the treatment group differed by just 0.05 from that of the non-treatment group.

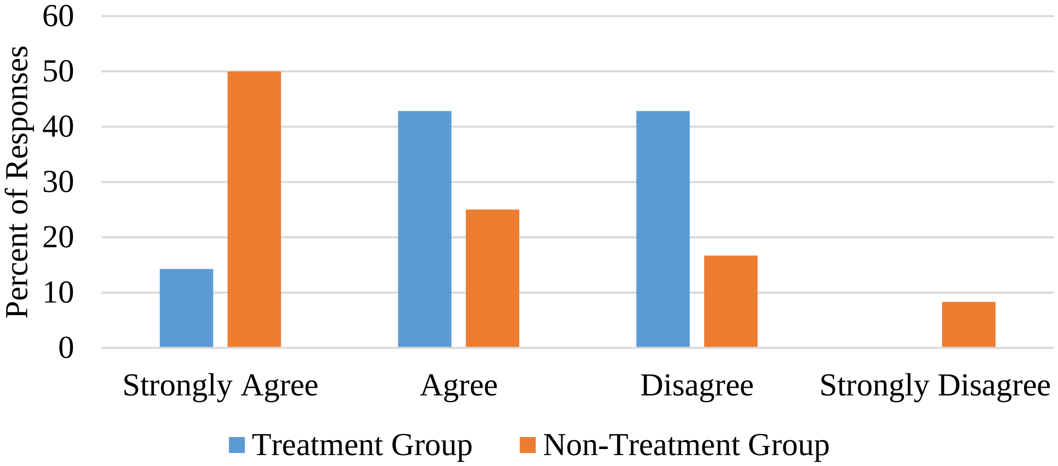

Figure 5. Ryerson mid-treatment survey (round 2) question: "I am more comfortable than I used to be when I don't have instructions on what to do next," (*N*=22).

During the first round of treatment the Ryerson Mid-Treatment Survey asked to students to respond to the prompt "when I complete experiments in this class, I feel I have accomplished something." The treatment group's mean response was 0.37 higher than the non-treatment group, and the median value 1.0 higher (Figure 6). A randomization permutation test produced a p-value of 0.048.

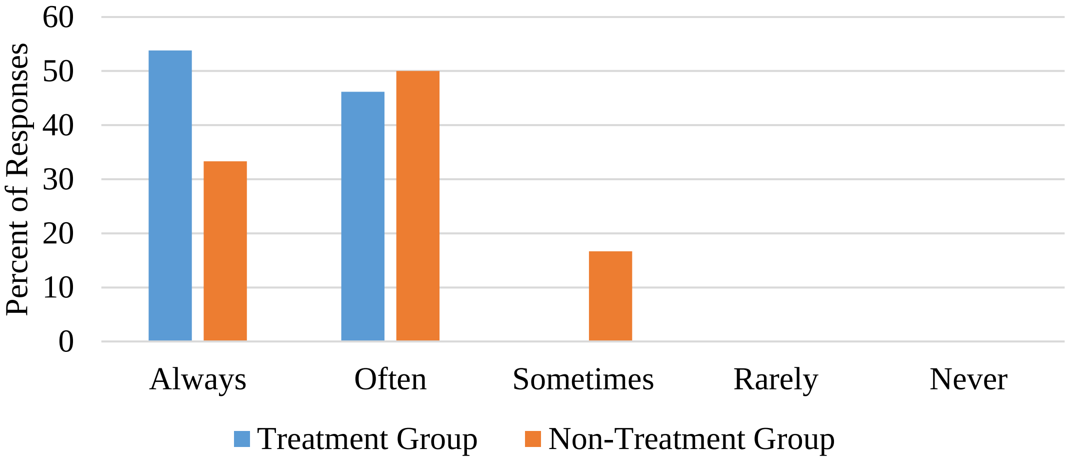

Figure 6. Ryerson mid-treatment survey (round 1) question: "When I complete an experiment in this class I feel I have accomplished something," (*N*=22).

During the second round of treatment, the Ryerson Mid-Treatment survey indicated that students feeling of accomplishment was not improved by the treatment. In fact, the non-treatment group responded more positively to the prompt “when I complete experiments in this class, I feel I have accomplished something,” providing a mean response that was 0.62 higher than that of the treatment group (Figure 7). A randomization test here yielded a p-value of 0.059.

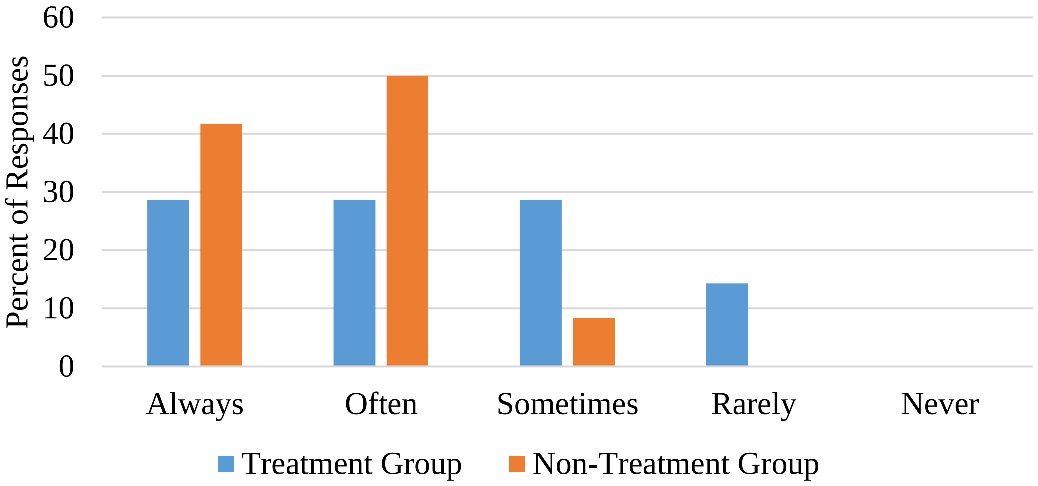

Figure 7. Ryerson mid-treatment survey (round 2) question: “When I complete experiments in this class, I feel I have accomplished something,” (*N*=22).

The first iteration of the Ryerson-Post Treatment Survey showed that students in the treatment group were more proud of their work than students in the non-treatment group (Figure 8). As before, responses were assigned numbers and the mean response of the treatment group was 0.44 higher than that of the non-treatment group. A randomization permutation test gave a p-value of 0.047.

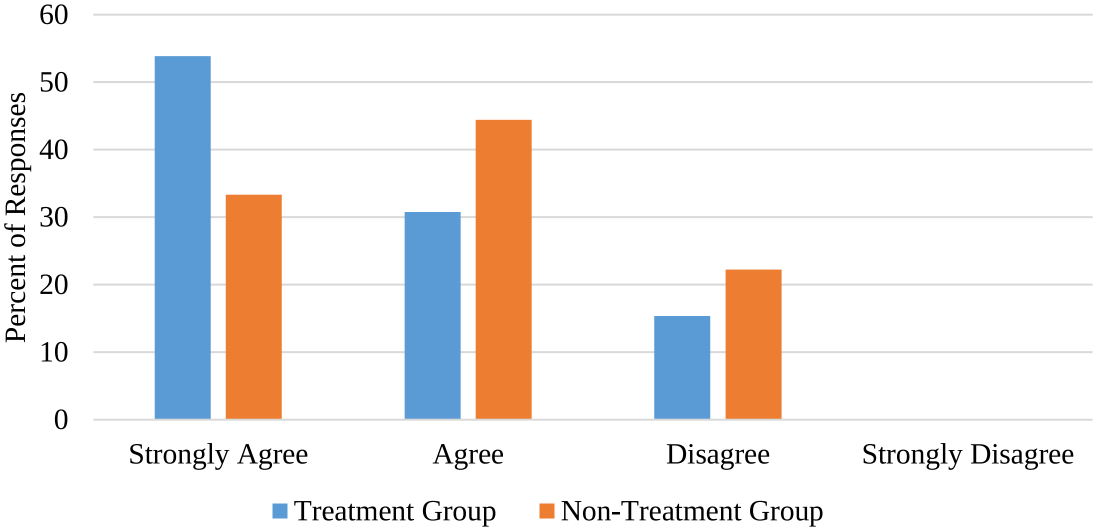

Figure 8. Ryerson post-treatment survey (round 1) question: “I am proud of the lab reports I submitted,” (*N*=22).

However, during the second round of treatment the Ryerson Post-Treatment Survey results showed that the treatment group was not as proud of their work as the non-treatment group. In the treatment group, a combined 72% of students chose Strongly Agree or Agree when prompted with “I am proud of the lab reports I submitted. In the non-treatment group, 100% of students chose Strongly Agree or Agree (Figure 9).

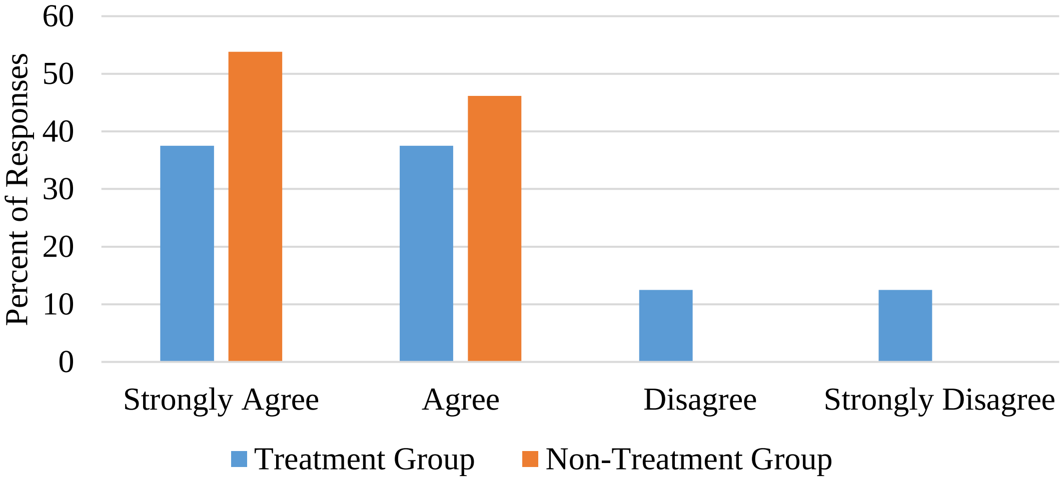

Figure 9. Ryerson post-treatment survey (round 2) question: “I am proud of the lab reports I submitted,” (*N*=22).

The first round Ryerson Post-Treatment Survey also indicated that students in the non-treatment group found the experiments more challenging than students in the treatment group (Figure 10). The mean response for this question from the treatment group 0.51 lower than the mean responses from the non-treatment group. A randomization test yielded a value of 0.023 for the responses to this question. During interviews, one student in the treatment group remarked “the labs are challenging, but in a different way – instead of making sure I haven’t missed a step, I have to come up with the steps. I think it’s more fun so it doesn’t seem as difficult.”

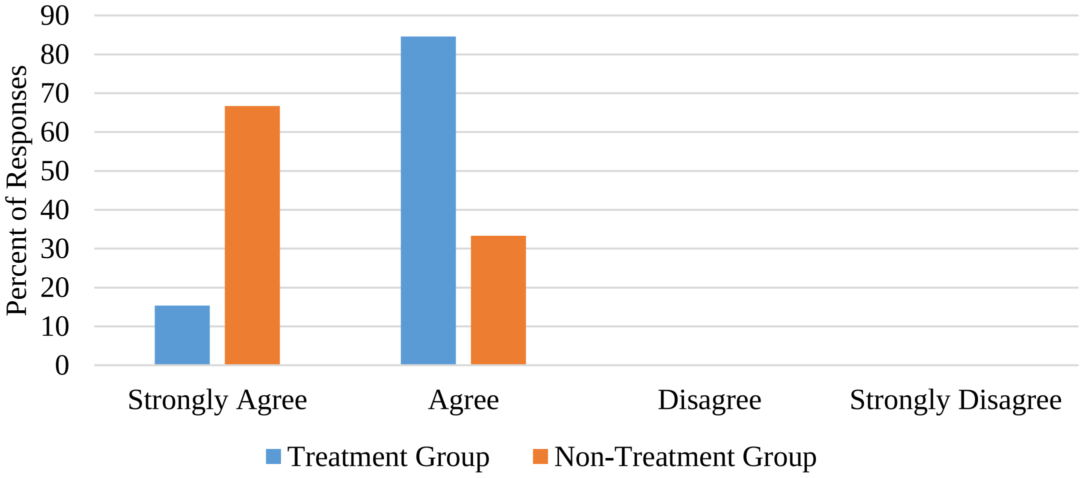

Figure 10. Ryerson post-treatment survey (round 1) question: “The experiments done on Forces and Newton’s Laws were challenging,” (*N*=22).

In the second round of treatment, there did not appear to be a difference between how challenging the two groups found the experiments to be (Figure 11). On the Ryerson Post-Treatment Survey, the mean response of the treatment group was 0.14 higher than the treatment group, however a randomization test yielded a value of 0.283.

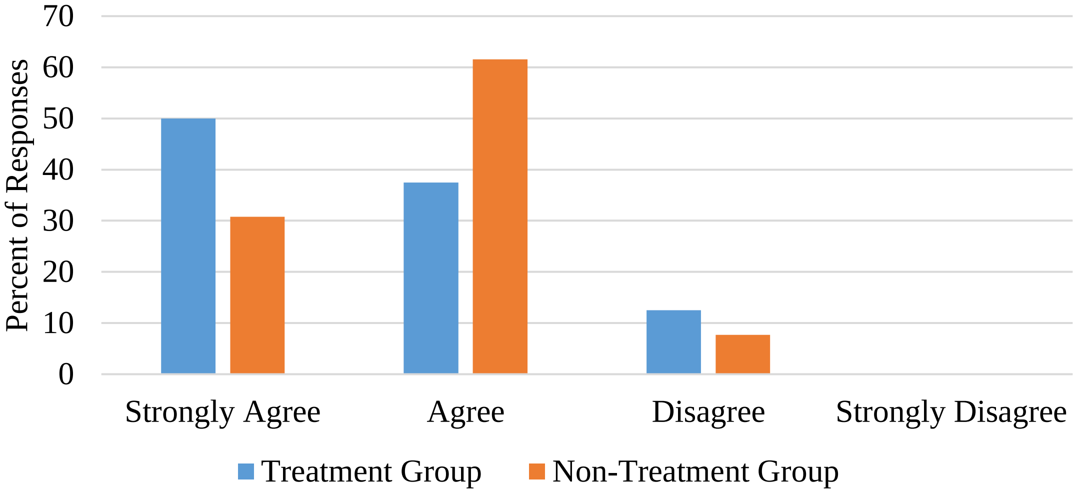

Figure 11. Ryerson post-treatment survey (round 2) question: “The experiments done on Work and Energy were challenging,” (*N*=22).

At the end of the first round of treatment, students in both groups were asked what they would change about the experiments they performed. In the treatment group, 46% of students said they would not change anything, 15% asked for more guidance, and 23% indicated they would like more freedom and less guidance. One student in the first-round treatment group wrote “give more time on labs so we can try multiple methods and compare results.” Another student took a somewhat different approach to her feedback, writing “changing to instruction[s] was WACK.” Meanwhile, of students in the non-treatment group, 22% wanted more guidance or detailed instructions, 11% said they would not change anything, and 0% asked for more independence (Figure 12).

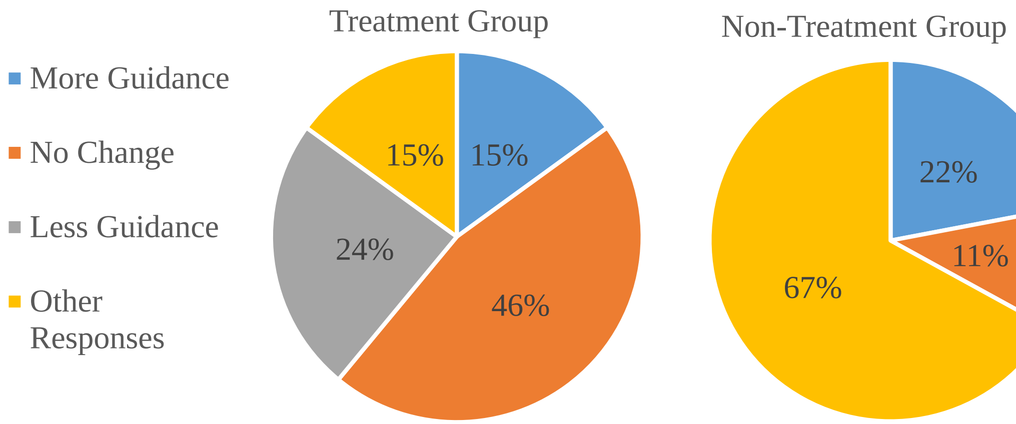

Figure 12. Ryerson post-treatment survey (round 1) question: “If you could change how we do experiments, what would you change?” (*N*=22).

At the end of the second round of treatment, when asked what they would change about experiments, 22% of the treatment group requested more guidance, while 11 % asked for less guidance and 22% said they would not change anything. In the non-treatment group, 15% said they would like more guidance and only 8% asked for less guidance (Figure 13). In both rounds of treatment, the treatment group included a larger percentage of students indicating that they would have liked more freedom and independence.

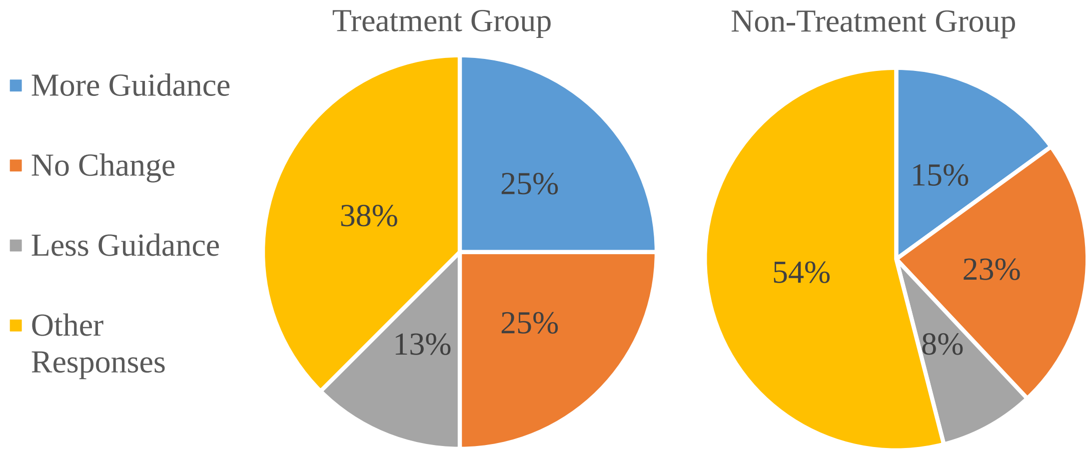

Figure 13. Ryerson post-treatment survey (round 2) question: “If you could change how we do experiments, what would you change?” (*N*=22).

The mean quiz grade earned by students in the treatment group was 4.74, while the mean grade earned by students in the non-treatment group was 5.06 on Blair Academy's 6.0 grading scale. A randomization test performed on the quiz grades yielded a p-value of 0.250, suggesting that there was not a statistically significant difference between the groups. Quiz results during the second round of treatment showed the treatment group performed slightly better than the non-treatment group. The mean score of the treatment group was 0.35 higher than that of the non-treatment group – 4.43 compared to 4.78. A randomization test on the quiz scores from the two groups this time yielded a p-value of 0.103.

A summative test was taken at the end of the unit, which was also the end of the each round of treatment. In the first round, the treatment group's mean score was 4.36, while the mean score of the non-treatment group was 4.06 (Figure 14). A randomization test on these scores gave a p-value of 0.215, again pointing to little significant effect, despite what the average values seem to indicate.

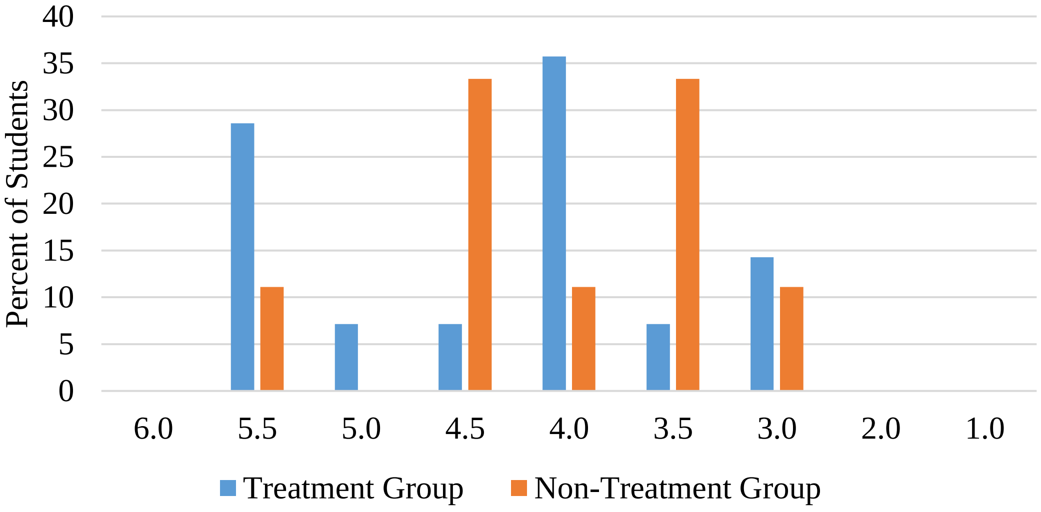

Figure 14. Test scores at the end of the first round of treatment, (*N*=22).

Test scores showed a similar pattern at the end of the second round of treatment, with the treatment group earning a mean score of 4.38 and the non-treatment group scoring a mean of 4.13 (Figure 15) . However, a randomization test performed on test scores produced a p-value of 0.165, showing that the distribution of the groups was not significantly different.

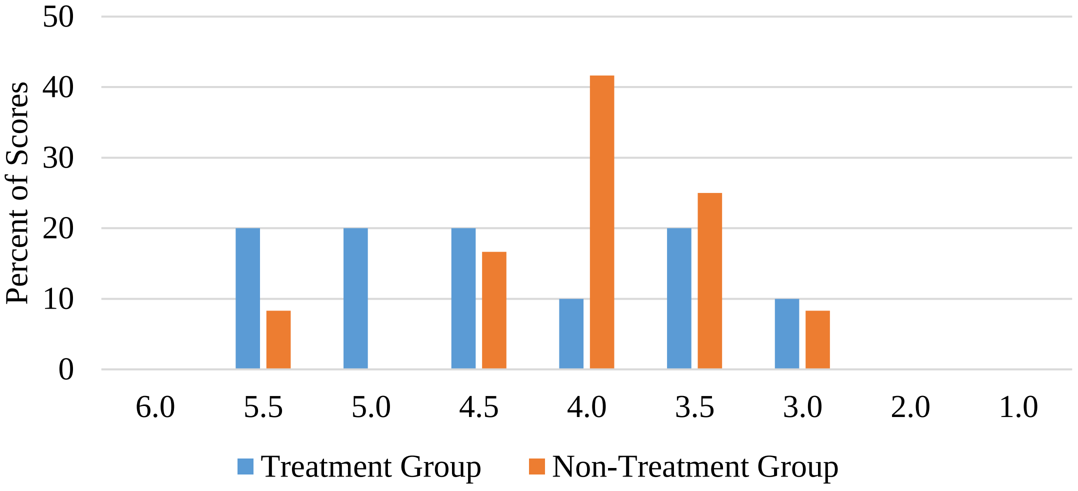

Figure 15. Test scores at the end of the second round of treatment, (*N*=22).

Over the course of three experiments the treatment group and the non-treatment groups earned nearly identical average grades of 4.98 and 4.94 respectively. Observations by the instructor while grading reports note that there was little detectable variation between the writing of treatment and non-treatment group students.

When lab reports were analyzed during the second round of treatment, the two groups were once again nearly identical, though only on the first lab report. The first report yielded mean scores of 4.92 and 4.89 for the treatment and non-treatment groups respectively. However, on the second lab report, the non-treatment group’s grades saw a notable uptick, averaging 5.56, while the treatment group grades improved only slightly to a mean of 5.03. Instructor’s notes indicate that the large jump in grades for the non-treatment group is due to rapidly improving scientific writing skills among the highest achieving students in particular. Some of these individuals improved their lab report grades by a full 1.0 or more.

On the Ryerson Post-Treatment Survey, administered after the second round of treatment, all students were asked which type of experiment they preferred (Figure 16). In the treatment group, 37.5% of students chose experiments without instructions, while 62.5% chose experiments with instructions. In the non-treatment group it was almost exactly the opposite, with 61.5% choosing experiments without instructions and 38.5% choosing experiments with instructions.

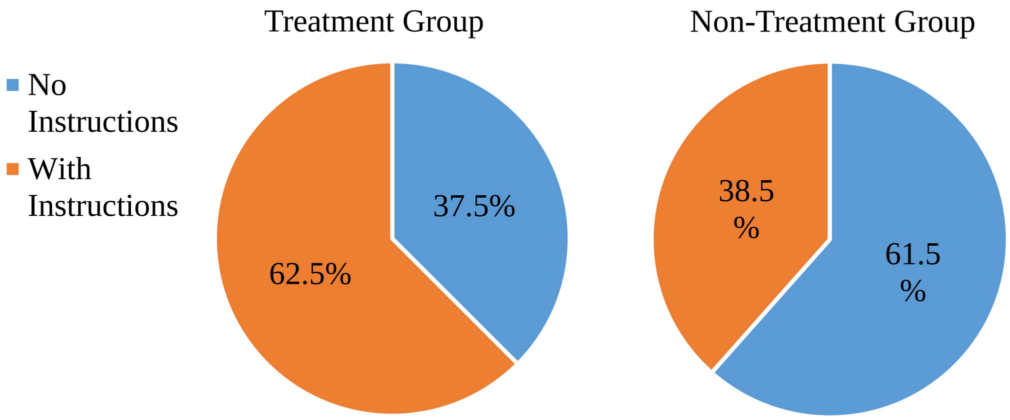

Figure 16. Ryerson post-treatment survey (round 2) question: “Which type of experiment did you prefer?” (*N*=22).

When asked why they felt this way, students who preferred inquiry experiments, without instructions, said things like “it forces me to completely understand the process before I do it,” “I felt that while they were harder they helped us understand the topics more,” and “figuring out how to go about doing something seems just as important to me as actually doing it.” Students who indicated that they preferred to be provided with instructions said “it would be really hard to write lab reports if the labs get completely messed up,” “it’s efficient,” and “I usually get lost when we only have [a] question without any instructions.”

INTERPRETATION AND CONCLUSION

During the first round, the treatment group was more comfortable without instructions, felt more accomplished and prouder of their work, and found the experiments less challenging than the non-treatment group. At the conclusion of round one, some of students the treatment group also asked for even more freedom in future labs, whereas the non-treatment group included no such responses. However, during the second round of treatment, nearly all of these effects went away.

During the second round, the treatment group did not feel comfortable without instructions, but the non-treatment group (the same students who received the treatment in the first round) did. This could be attributed to the fact that the first round of treatment was conducted early in the year, while students were still forming habits in the laboratory. The first treatment group learned to conduct their AP Physics experiments in a guided inquiry setting, while the first non-treatment group grew accustomed to having specific instructions and a prescribed apparatus. Once those habits formed, they may have been difficult to shift during the second round of treatment, which was conducted during the second half of the school year. Students experiencing inquiry investigations for the first time often struggle with the transition from confirmation inquiry (Arslan, 2014). Perhaps what was observed in this study was a small-scale version of that very same effect. Survey responses clearly show that the group who received the treatment during the first round preferred the guided inquiry experiments, while the other group preferred the traditional experiments, even after both groups had experienced the treatment.

For future action research projects, each round of treatment could be made shorter and both rounds conducted relatively early in the school year so that both groups have the chance to develop the proper habits of mind and experimental practices needed to succeed in a guided inquiry setting. Alternatively, a transition period could be used to help students learn how to function properly without specific instructions. The group receiving the treatment during the second round could, for example, perform a few simple activities or experiments without instructions before taking on a full-scale inquiry experiment. This might help ease the transition and build students' confidence in their ability to solve problems and enact solutions.

Survey responses in the second round of treatment also indicated that the group who received the treatment first still felt more accomplished and prouder of their work in experiments. One possible reason for this may be that the students who happen to be in that group innately take more pride in their work than students in the other group and often feel a strong sense of accomplishment when completing tasks. The difference in survey responses may have nothing to do with the treatment.

Additionally, this same group felt the labs were less challenging in both rounds of treatment, regardless of which type of lab they were performing. Again, this may have to do with the nature of these students in particular, though perhaps not. It is possible they were better prepared, having developed the positive habits of mind needed to successfully perform experiments as a result of experiencing the treatment early in the year.

Analysis of test, quiz, and lab report grades showed no impact from the treatment in either round. This is consistent with the work of Kirschner, Sweller, & Clark (2006) who found that learning outcomes are roughly equivalent when comparing traditional and inquiry-style instruction.

VALUE

During this study the students were exposed to how uncertain and flummoxing the world of scientific experimentation can be when you have to make your own decisions. They were forced to use their imagination and creativity along with their scientific and mathematical skill to put together an experiment that could answer the question posed to them. I am certain that even those who did not show any measurable gains in survey questions or on summative assessments benefited from the experience.

There were two students in particular whose experience I consider an important representation of the impact of guided inquiry experiments. These two are not academically high-achieving, in fact they are in the bottom third of their class, and showed no measurable gains as a result of the treatment. One of them actually told me on a number of occasions that she simply does not like physics. However, they were both quite good at thinking creatively to design experiments. When forced to go from the inquiry experiments back to traditional, they were disappointed, having clearly enjoyed the process of determining their own path. Their quotes of “aw man, instructions? This is boring,” and “changing to instruction[s] was WACK” will stay in my memory for many years. The critical point here for me is that students’ creativity and ingenuity does not always correlate directly with the skills and abilities we normally measure to determine their grades. Despite their mediocre test scores and below average lab reports, these two students excelled at designing and troubleshooting experiments.

The creativity of my students is probably what impressed me most throughout this study. When I was constructing guided inquiry experiments, I generally started with a traditional experiment, broke it down to the essential question that was being answered, then removed all the framework around it leaving only the question. Each time, I had in mind a few different ways students could design an experiment that would successfully collect data that could be used to answer the question. However, during each and every experiment, at least one group thought up an idea that had not occurred to me. Without my initial direction limiting their scope, some students were able to see a completely different way to find an answer.

I have learned a great deal about teaching young students how to explore natural phenomena independently. I thoroughly enjoyed changing my practices in the laboratory. Experiments were more interactive for me as I was involved in helping students through the design process and thereafter troubleshooting their experiment when things went awry. It was challenging to find the right balance at times. I wanted to give the students enough guidance to “grease the wheels” a bit, but no so much that I removed their responsibility over and ownership of the experiment. As I got more practice, I got better at trusting my students to work things out on their own. I would answer questions that were directly asked, and give a gentle nudge or hint to any group who I could tell was overlooking an important element.

While my experience has been a very positive one, and I believe my students have grown as well, I wonder what the impact of this kind of treatment would be on students at lower levels of physics. Students in AP Physics are self-selecting to be driven and dedicated to learning. Their motivations may be grade-based rather than purely for the pursuit of knowledge, but in either case their effort generally cannot be questioned. This is also largely true for Physics Honors students at Blair Academy, however students who take our lowest level of Physics are often only in the class because it is a requirement for graduation. The experience of the two students described above who do not earn the highest grades but enjoyed and excelled at experimental design nonetheless gives me some hope that lower level students would enjoy and benefit from guided inquiry experiments. However, I wonder if a lack of enthusiasm for their academics, or in physics in particular, would prevent them from putting their full effort into uncertain situations like experimental design. I do not know yet what levels of physics I will be teaching in the years to come, but I will certainly be incorporating guided inquiry learning for my future students while I gather more data and information about its impact on their overall experience in class.

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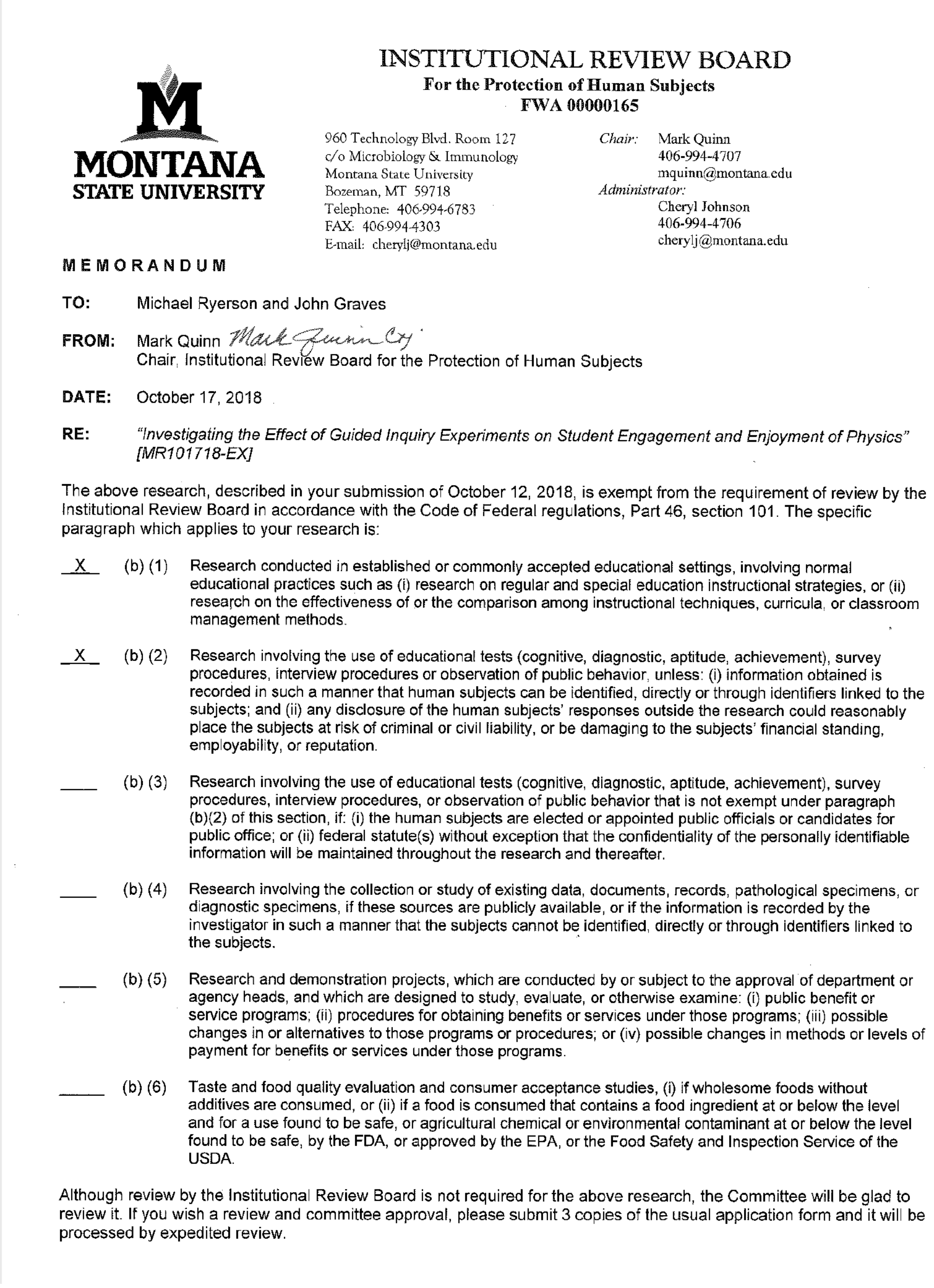
APPENDICES

APPENDIX A

MONTANA STATE UNIVERSITY INSTITUTIONAL REVIEW BOARD EXEMPTION



MONTANA
STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD
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Administrator:
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MEMORANDUM

TO: Michael Ryerson and John Graves

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

DATE: October 17, 2018

RE: *"Investigating the Effect of Guided Inquiry Experiments on Student Engagement and Enjoyment of Physics" [MR101718-EX]*

The above research, described in your submission of October 12, 2018, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

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

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

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

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

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

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

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

APPENDIX B

RYERSON PRE-TREATMENT SURVEY

This short survey will serve to give me an impression of your past experiences and your feelings toward science class and science experiments in particular. Please note that Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way. Thank you!

1. I enjoy science classes
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
2. I consider myself a strong science student
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
3. I look forward to labs or experiments in class
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
4. When I complete an experiment, I feel I have learned something new
    a. Always
    b. Often
    c. Sometimes
    d. Rarely
    e. Never
5. When I complete an experiment, I feel like I have accomplished something
    a. Always
    b. Often
    c. Sometimes
    d. Rarely
    e. Never
6. Generally speaking, I am uncomfortable when I do not know what to do next in experiments
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree

7. When I submit a lab report, I am proud of my work
    a. Always
    b. Often
    c. Sometimes
    d. Rarely
    e. Never
8. Which of the following best describes the experiments you have done in science class?
    a. I am given specific instructions, and I am expected to get a specific result
    b. I am given general guidelines, and I am expected to prove/disprove a certain idea
    c. I am given a question to answer, and the design of the experiment is up to me
    d. I choose a question to pursue and design an experiment to try and find an answer
9. Which of the following best describes your approach to science class?
    a. I sit in the front and frequently ask/answer questions
    b. I listen attentively, but do not often speak up unless called on
    c. I pay attention, but try not to be noticed or called on
    d. I am only there because I have to be
10. Which statement best describes your experience with science teachers?
    a. My teachers mostly lecture and I try to absorb as much information as I can without getting overwhelmed
    b. My teachers engaged me in discussion through questions and example problems to teach concepts
    c. My teachers give me hands-on tasks to help me learn new ideas
    d. My teachers frequently vary their approach, using many different means of teaching new ideas
11. Why do you think all science classes include labs/experiments?
12. Briefly describe the best or most memorable experiment you have ever done in a science class.
13. Is there anything else you would like me to know?

APPENDIX C

PRE-TREATMENT INTERVIEW QUESTIONS

1. How do you feel about science experiments?
2. What do you think is the purpose of having experiments in science class?
3. Do you feel like they help improve your understanding?
4. Do you generally feel actively engaged in experiments?
5. Do you generally like more guidance or more freedom during experiments?
6. What do you think of lab reports? Are you generally proud of the work you produce?
7. Can you briefly describe the best or most memorable experiment you’ve ever done?
8. If you were designing a experiment for our class, what would it look like?

APPENDIX D

RYERSON MID-TREATMENT SURVEY

Please note that Participation in this research is voluntary and participation or non-participation will not affect a student’s grades or class standing in any way. Thank you!

1. I am enjoying this class
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
2. The experiments in this class are interesting to me
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
3. When I complete the experiments in this class, I feel I have learned something new
    a. Always
    b. Often
    c. Sometimes
    d. Rarely
    e. Never
4. When I complete experiments in this class, I feel I have accomplished something
    a. Always
    b. Often
    c. Sometimes
    d. Rarely
    e. Never
5. I like designing aspects of the experiment on my own
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
6. I am more comfortable than I used to be when I don’t have instructions on what to do next.
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree

7. I am proud of the lab reports I have written in this class
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
8. Overall, I feel more excited by and interested in experiments in this class compared to my other science courses
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
9. I feel more interested in the class overall because of the experiments we do.
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
10. If you could change how we do labs and experiments, what would you change?
11. Is there anything else you would like me to know?

APPENDIX E

RYERSON POST-TREATMENT SURVEY

Please note that participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way. Thank you!

1. I enjoyed the experiments in this topic
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
2. The experiments in this topic helped me better understand the course content
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
3. I am better at designing experiments than I was before this topic
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
4. I am proud of the lab reports I submitted
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
5. The experiments done in this topic were interesting
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
6. The experiments done in this topic were challenging
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
7. I am more comfortable than I used to be when I don't have instructions on what to do next.
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree

8. Overall, I feel more excited by and interested in experiments in this class compared to my other science courses
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
9. I feel more interested in the class overall because of the experiments we do.
    a. Strongly Agree
    b. Agree
    c. Disagree
    d. Strongly Disagree
10. If you could change how we do labs and experiments, what would you change?
11. Which experiment, if any, was your favorite or especially memorable? Why?
12. Is there anything else you would like me to know?

APPENDIX F

MID-TREATMENT INTERVIEW QUESTIONS

1. What do you think of the experiments we’re doing?
2. Would you say these experiments are more engaging, less engaging, or the same as experiments from other science courses?
3. What do you like about the experiments?
4. What don’t you like about the experiments?
5. How do you feel about your lab reports for these experiments so far?

APPENDIX G

POST-TREATMENT INTERVIEW QUESTIONS

1. What did you think of the experiments we did?
2. What did you like about the experiments?
3. What didn’t you like about the experiments?
4. Would you say you were more actively involved in performing the experiments compared to the other science courses you have taken?
5. How did it feel to make your own decisions about how an experiment was going to be performed?
6. Would you have preferred to have a list of instructions for the experiments we performed?