

COMBINED USE OF MUDDIEST POINT AND APPLICATIONS CARDS IN HIGH SCHOOL
SCIENCE

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DEDICATION

When I started the MSSE program, my wife was pregnant with our son. Now we have a sweet, playful, curious little 2-year-old. I dedicate this to my wife for encouraging me to take up this program and for supporting me so lovingly throughout it, and to my son who has become my purpose for most things I do.

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ABSTRACT

The purpose of this Capstone Project was to determine the impact of the combined use of the Muddiest Point and Applications Cards formative assessment techniques on the performance and attitudes of ninth grade Introduction to Physical Science students. The study took place over the course of 2 units. The first unit was presented in the teacher's standard manner, while the second unit included the use of the formative assessments. Data was collected through a pretest and posttest, surveys, and student interviews. The results of the pre and posttests showed no significant improvement in student performance as a result of the treatment. Pre and posttreatment surveys and posttreatment interviews indicated that the majority of students thought the Muddiest Point was useful, but most changes between the surveys did not prove to be statistically significant. Interviews indicated that some students could see the potential use of the activities, but they did not think that they personally gained much from them.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

Context of the Study

The Academy of the New Church (ANC) is a small, private high school in Bryn Athyn, Pennsylvania. The school has 188 students from ninth through 12th grades. The school has about 28% minority students (US News, n.d.-a; US News, n.d.-b) and a 7:1 student to teacher ratio (ancss.org, n.d.). Approximately 12% of the student body is eligible for free or reduced lunch (J. Irwin, personal communication, November 3, 2025). Technically, ANC is comprised of a boys' school and a girls' school, but they largely operate as one school. One of the courses I teach at ANC is the Introduction to Physical Science (IPS). It is a required course for all ninth-grade students, and I teach the boys. Because every ninth-grade student takes IPS, there is a large range of academic strength in my students. I have some students who struggle immensely, while others breeze through with little effort.

In recent years, I have found that the portion of students who struggle in IPS has been increasing. I would like to find a way to help these students better understand and engage with the material. My background and training are as a chemist, not as an educator, so to better myself as a teacher I am currently pursuing my Master's of Science in Science Education Degree from Montana State University. From my studies and some research, I have concluded that my students would benefit from more formal formative assessment (FA) (Babinčáková et al., 2020). However, many FA techniques require considerable time to implement, and I would need to remove content from my course to accommodate these assessments. Because I teach at a private

school, I do have a fair amount of freedom to revamp my curriculum as I see fit, but a complete restructuring would be a years-long process. While I believe my students would benefit from more FA, I would have to balance that with my desire to avoid decreasing the amount of content I cover. Ideally, I would like to identify and implement a few simple FA techniques in the short term that have a strong impact on student performance.

To narrow down the FA techniques I wanted to implement, I first had to identify what I believed to be the sources of my students' struggles. As student performance has been decreasing, I have also noticed a decrease in active participation. This decrease in participation has manifested in two ways. Firstly, I have found that fewer students are asking questions or asking for help when they do not understand something. There could be many reasons for this. Perhaps the students are embarrassed to look foolish in front of their classmates, or maybe they are not used to having to advocate for themselves in an academic setting. Secondly, there is an increasing number of students who seem entirely disinterested or apathetic about the course material. I hear many students complaining about the fact that they have to learn science and wondering why they need to know the material at all. During class, I try to make the importance of the material clear, but that seems to be becoming less effective in piquing my students' interest.

After some research, I have decided upon two FA techniques that I hope will help to remedy both issues. They are the Muddiest Point and Applications Cards exercises (Angelo & Cross, 1993). Both techniques require a relatively small commitment of time and effort on both my part and the part of my students, and both have been shown to be effective in increasing student performance in science courses (Muteti et al., 2022; Sristy et al., 2023). The Muddiest

Point exercise involves asking students to anonymously write down what they found to be the most confusing topic covered in class. The teacher then reviews the students' submissions and addresses some of the most common questions in a subsequent class period. I hope that requiring students to participate in this exercise will give me high quality data as to what topics the students need more help with. Additionally, it will encourage students to spend time consciously reflecting on their understanding of the course material, which is a skill that I suspect they still need to develop. The Applications Cards exercise asks students to take a few minutes to write down what they believe to be a real-world application of the material that was covered in class. After reviewing the submissions, the teacher leads a short discussion about the students' ideas. I currently try to include real-world applications while I teach the material in my classroom, but I hope that shifting that burden to the students will increase their engagement with the material and help them to understand its relevance to their lives. Perhaps this exercise will even increase some of my students' interest in the sciences. I hope that the regular implementation of these two FAs will both increase student performance and have a positive impact on student attitudes toward science.

Focus Question

My focus question was, What is the effect of regular implementation of both Muddiest Point and Applications Cards on student performance and attitudes in high school science courses?

CHAPTER TWO

CONCEPTUAL FRAMEWORK

Use of Formative Assessment

The use of formative assessments (FA) in science courses has consistently been shown to improve student performance (Babinčáková et al., 2020). Formative assessments can be explained as relatively low stakes assessments of student knowledge that take place more frequently, and often less formally, than summative assessments. Summative assessments are typically graded assessments, such as tests and exams, that attempt to quantify the level of a student's understanding of the material. The use of FA can help teachers to understand their students' level of learning on a particular subject. It can also give teachers important feedback that can help them improve the effectiveness of their teaching (Angelo & Cross, 1993).

Babinčáková et al. (2020) found that the implementation of FA techniques in chemistry classes significantly increased the students' test performance as compared to those in a control group. The study involved 12- to 13-year-old students across five schools in Slovakia. At the beginning of the study, all classes were given a pretest to determine their chemistry knowledge and skills. The pretest did not show any significant difference in performance between the classes, so they were randomly assigned to the treatment and nontreatment groups. Both groups then started a 10-lesson unit on mixtures. The content of each lesson was standardized across the classes, but the treatment group instructors incorporated 11 different FA techniques into the lessons. The nontreatment group was taught the lessons in their normal fashion. At the end of the study, both groups were given a posttest on the material covered. The treatment group scored

significantly higher on the posttest than the nontreatment group. The treatment group was also given a questionnaire to determine their attitudes toward FA. Overall, the students had positive feelings toward FA. They reported that the lower stakes assessments before a summative test were helpful in identifying the areas in which they needed to improve.

While FA has been shown to be an effective tool to improve student performance, teachers are often resistant to incorporating FA techniques in their classrooms (Babinčáková et al., 2020). FA can be very time consuming. Teachers need to prepare, implement, and analyze the assessment before following up with the class to close the loop. This requires a considerable allocation of time that could be seen as taking away from time that could be used to teach new content or complete summative assessments that are viewed as more important (Edwards, 2022). Ideally, teachers could find and use forms of FA that are effective while requiring a minimal time commitment. Two very simple FA techniques with the potential to have a large impact are Muddiest Point (MP) and Applications Cards (AC) (Angelo & Cross, 1993).

Muddiest Point (MP)

MP is one of the simplest, least time-consuming FA techniques, and it has been shown to be very effective (Muteti et al., 2022). When implementing MP, teachers give students a few minutes to write down what they consider to be the least clear or most confusing topic that was covered in class that day. Typically, this takes place at the end of a class period. The teacher can then quickly read through the responses and address one or more of the most common responses at the beginning of the next class period (Angelo & Cross, 1993).

Muteti et al. (2022) conducted a study on the use of MP in a General Chemistry I course at a public research university. The study included two sections of the course and took place over

the course of an entire semester. The sections had two different instructors, but the instructors worked together to make the content as consistent as possible between the two sections. One of the sections was chosen as the treatment group and used the MP. To test the effectiveness of the MP, student scores on three midterm exams and a final exam were compared between the treatment and nontreatment groups. The study found that the treatment group scored significantly higher on all three midterm exams, but not on the final exam. The authors suggest the reason no significant difference was found on the final exam was that both groups suffered from cognitive overload due to the large amount of content covered by the exam.

Another phenomenon noted by Muteti et al. (2022) was that certain groups seemed to benefit to varying degrees from the implementation of MP in the classroom. While improvements in student performance on the midterms were found across the entire study population, their study found that marginalized, female, and minority students who identified as first generation showed even more improvement than other students. One explanation the authors suggest for this difference is that these students might not normally feel comfortable asking questions during class. The MP activity allows students to ask their questions anonymously, so it had the potential to collect input from students who might be too shy or embarrassed to ask in front of their classmates.

Oguguo et al. (2025) conducted an experiment comparing the effectiveness of MP to Think-Pair-Share, another popular FA technique. The study found that students using MP had significantly better retention of mathematics concepts than those using Think-Pair-Share. The study concluded by recommending that all mathematics teachers adopt the use of MP due to its

proven ability to increase both student performance and retention. It is this combination of relative simplicity and effectiveness that makes MP such an attractive choice for educators.

Applications Cards

Using Applications Cards is another relatively low-effort FA technique that has the potential to improve both student performance and attitudes in science courses (Pietruszewski, 2020). In the AC activity, after a lesson, teachers give students index cards or pieces of paper and ask them to write down at least one possible real-world application for the material that was covered in class. Teachers then read through the cards and choose a few noteworthy responses to discuss with the class later. This activity asks students to think critically about the content they learned, which has the potential to strengthen their understanding of the material. The realization that the material learned in class has practical applications in the real world can also positively impact students' interest and motivation in the classroom (Angelo & Cross, 1993).

Majid and Rohaeti (2018) showed the positive impact that having context for chemistry content can have on both student achievement and attitude. Their study included two classes of chemistry students in Indonesia. The class chosen as the treatment group was given context-based lessons about acids and bases, while the nontreatment group received more traditional lessons on the subject. The context-based approach places extra emphasis on the real-world applications of the content by giving examples that relate the material to the everyday life of students. At the conclusion of the unit, both groups were given a posttest to assess their understanding of the material and a questionnaire aimed at determining their attitude toward the course. The study found that the treatment group scored significantly higher on the posttest and reported higher levels of motivation and a more positive attitude toward learning the material.

Sristy et al. (2023) carried out a similar study on General Chemistry I students at Oklahoma State University. Two lecture sections were selected for the study, one of which was chosen as the treatment group. The study took place over the course of a semester. For the first half of the semester, both groups received similar instruction including interactive lectures, decontextualized online quizzes, and homework. At the end of the first half of the semester, both groups were given a mid-survey that served as the pretest for the study. For the second half of the semester, the instruction technique for the treatment group changed to include contextualized online quizzes and the implementation of AC activities. Rather than being performed in class, the AC activity was completed online outside of class, so it did not take up any lecture time. At the end of the semester both groups were given an identical cumulative final exam that was developed by both instructors. This served as the posttest in the study. Both groups were also given post surveys to determine their perception of the relevance of the course content. The study found that the treatment group performed significantly better on the final exam than the nontreatment group. The results also showed a positive impact on the students' perceived relevance of the course content. This study suggests that connecting science content to their everyday lives can improve students' achievement and attitudes toward science.

Implementation

The use of various FA techniques has the potential to greatly improve student achievement, but the time commitment required is daunting for many teachers (Babinčáková et al., 2020). The ideal solution for both teachers and students is a set of FA techniques that deliver the maximum amount of impact on student learning with a minimum impact on teacher workload. The Muddiest Point and Applications Cards techniques individually improve student

performance, and they both require minimal adjustment to course structure (Muteti et al., 2022; Sristy et al., 2023). Depending on the specific issues within a classroom, the combination of the two techniques might be the ideal way for a teacher with limited time to create measurable changes in students' performance.

CHAPTER THREE

METHODOLOGY

Demographics

The Academy of the New Church (ANC) is a small, private high school in Bryn Athyn, Pennsylvania. The school has 187 students from ninth through 12th grades. The school has about 28% minority students (USA News, n.d.-a; USA News, n.d.-b) and a 7:1 student to teacher ratio (ancss.org, n.d.). ANC is a private school that draws some students from outside the immediately surrounding community and includes a small population of boarding students, therefore the demographics of the student body do not reflect those of the town of Bryn Athyn. For example, the residents of Bryn Athyn are 94% white, which is considerably higher than the proportion of white students enrolled at ANC. The median household income in Bryn Athyn is nearly double that of the state of Pennsylvania, but that does not necessarily reflect the economic breakdown of ANC's student body (Census Reporter, 2023).

This research was conducted in the Introduction to Physical Science (IPS) course that I teach to ninth-grade boys. This is a year-long course that covers basic science skills, chemistry, and physics. ANC uses a trimester system, where most academic courses continue throughout the whole year. Because every ninth-grade student is required to take IPS, there is a large range of academic strength in my students. I have students who struggle immensely, while others breeze through with little effort. The students represented in this study were split into two class sections which met at different times. Between the two sections, there were 23 students. One section contained 11 students while the other had 12.

Treatment

This study took place over the course of the winter term of the 2025-26 school year. In that time, we covered two units of material (Units 3 and 4). Unit 3 covered atomic structure and the organization of the periodic table. Unit 4 covered bonding, nomenclature, and chemical reactions. Historically, most students have done fairly well in Unit 3, but they have tended to struggle in Unit 4. Both sections of IPS received the same treatment at the same time. The treatment was applied to both sections during Unit 4, while Unit 3 was taught without treatment using my usual methods. The treatment involved the implementation of both the Muddiest Point (MP) and the Applications Cards (AC) formative assessment techniques.

Muddiest Point

The MP assessment was carried out at the end of every class in which the students learned new concepts. I gave the students a few minutes at the end of class to respond to the question, What were your muddiest points in class today? What topics are you struggling with the most?. I collected students' anonymous responses digitally using Google Forms. Before the class's next meeting, I analyzed the responses for themes and determined which topics the class could use some more time with. At the beginning of the following class, I took five to 10 minutes to quickly address some of the more common student responses to the MP and to review the relevant topics.

Applications Cards

The AC assessment was carried out once during every week of Unit 4 in which we covered new topics. I made a Google Form and assigned it as homework. The form asked for a

response to the prompt, Thinking about the topics we covered this week, briefly describe what you believe to be a real-world application of one of the concepts. If you are having a hard time thinking of one on your own, spend a few minutes researching it. After the students completed their responses, I read through them and took note of any that stood out as especially important or interesting. In a subsequent class period, I led a brief discussion about the applications of the content. I asked students to volunteer what they had come up with, and I called attention to the responses that I found notable.

The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for work with human subjects was maintained (Appendix A).

Data Collection and Analysis Strategies

To determine the effect of these formative assessment techniques on student performance, students completed pre and posttests at the beginning and the end of Units 3 and 4. The Unit 3 Pretest consisted of 26 multiple-choice questions that related to the major topics that were to be covered in Unit 3 (Appendix B). The Unit 3 Posttest contained 26 similar, but not identical, multiple-choice questions on the same material (Appendix C). Similarly, the Unit 4 Pretest and Unit 4 Posttest each contained 15 similar questions that related to the content covered in Unit 4 (Appendices D & E). The results of these tests were analyzed for normalized gains, and correlations to determine whether the treatment had significantly impacted student performance.

Surveys were used to collect data about student attitudes toward science courses. The students were given the Pretreatment Survey after Unit 3 but prior to starting the treatment in Unit 4 (Appendix F). The survey consisted of 12 Likert-style questions that asked students the

extent to which they agreed with statements about science. The response options for the questions were disagree, tend to disagree, tend to agree, or agree. There were also two free-response questions that asked for additional comments about the applicability and difficulty of the material they learn in their science courses. After the treatment, students completed the Posttreatment Survey which contained all the same questions as the Pretreatment Survey and a few additional questions. The additional questions focused on the students' experiences with the MP and AC activities. The Likert-style questions were analyzed using frequency analysis, and the free-response questions were analyzed for themes. Chi squared tests were used to determine whether any differences were statistically significant.

Data concerning student attitudes was also collected through small group interviews. The interviews were conducted after the treatment, and the questions focused on the students' feelings about the MP and AC activities (Appendix G). The audio of the interviews was recorded, and then the student responses were transcribed digitally. The goal of the interviews was to determine whether students felt that MP and/or AC helped to improve their performance, confidence, and interest in science. After student responses were transcribed, they were analyzed for themes. The data triangulation matrix shown in Table 1 shows the study's focus question and the data collection instruments that were aimed at answering it.

Table 1. Data triangulation matrix.

Focus Question	Data Source #1	Data Source #2	Data Source #3
What is the effect of regular implementation of both Muddiest Point and Applications Cards on student performance and attitudes in high school science courses?	Pre and Post Tests	Pre and Posttreatment Surveys	Small Group Interviews

CHAPTER FOUR

DATA ANALYSIS: CLAIMS AND EVIDENCE

Results

The goal of this study was to determine the impact of these FA techniques on student performance and attitudes in a high school science course. Quantitatively, the results of this study do not show a significant impact on either student performance or student attitudes. There were some indications that students found parts of the treatment to be useful, but that was not reflected in the results of the statistical analysis. Student interviews revealed that some students saw the potential in the treatment to produce positive gains but also provided some insight as to why they may not have.

Student Performance

The pre and posttests for Unit 3 were analyzed as follows. The average scores for the Unit 3 pretest and posttest were 27% and 79% respectively ($n=14$). Normalized gains were calculated for each student, and the average of the gains was found to be .72. This represents a high gain as classified by Hake (1998), the originator of the normalized gains test. A Pearson correlation coefficient analysis showed no significant correlation between pre and posttest scores. The pre and posttests for Unit 4 were analyzed using the same tests. The average scores for the Unit 4 pretest and posttest were 39% and 66% respectively ($N=15$). Normalized gains were calculated for each student, and the average of the gains was found to be .42. This corresponds to a medium gain as classified by Hake. A Pearson correlation coefficient analysis showed no significant correlation between pre and posttest scores.

Comparison of the results between the two units revealed that average normalized gains were substantially higher in Unit 3 than in Unit 4. The range of scores in Unit 3 was also smaller than those in Unit 4 (Figure 1). A Pearson correlation coefficient analysis showed that there was significant positive correlation ($p < 0.05$) between individual students' normalized gains in Units 3 and 4, meaning, for example, that a high normalized gain in Unit 3 correlated with a high normalized gain in Unit 4.

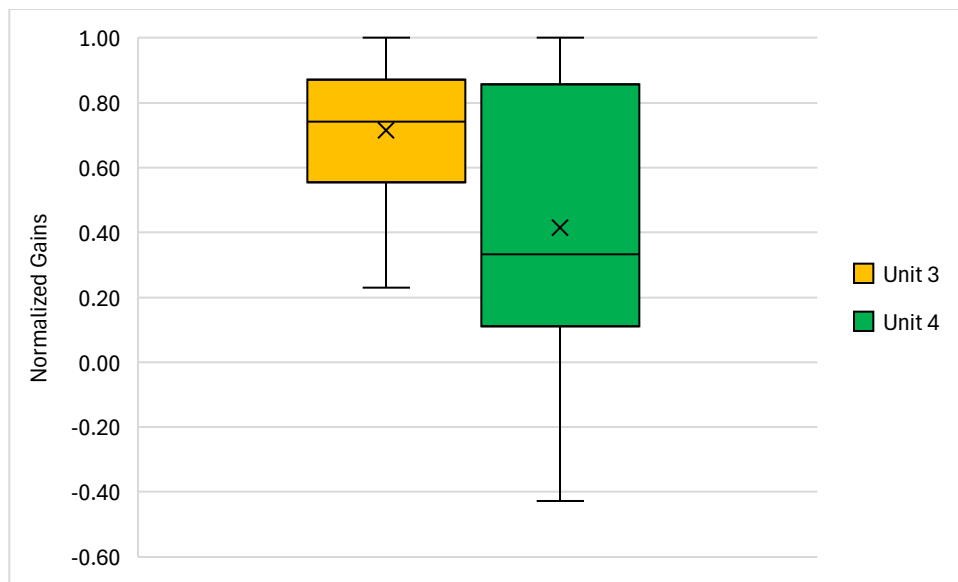


Figure 1. Normalized gains of Unit 3 vs Unit 4, (Unit 3 $n=14$ and Unit 4 $N=15$).

Student Attitudes

Analysis of pre and posttreatment surveys did not show a profound effect on student attitudes (Figure 2). The surveys asked students the extent to which they agreed with a number of statements. For the sake of analysis, each response was assigned a point value. Agree corresponded to 4 points, Tend to Agree to 3 points, Tend to Disagree to 2 points, and Disagree to 1 point. Some of the statements were worded positively, while others were worded negatively. In an effort to make data visualizations more clear, the results for the negative statements were

reversed (indicated with an R) so that a positive response corresponded to a higher point value. All responses that one would consider positive end up on the same side of a chart. There were some differences between the pre and posttreatment results. For example, in the pretreatment survey 64% of respondents agreed to some extent with the statement My studying at home is more useful than what we do in class, while only 43% agreed on the posttreatment survey. The percentage of students who stated that they felt confident they could get a good grade in science increased by 14% between the pre and posttreatment surveys. Chi squared analysis, however, did not find any of the differences to be statistically significant.

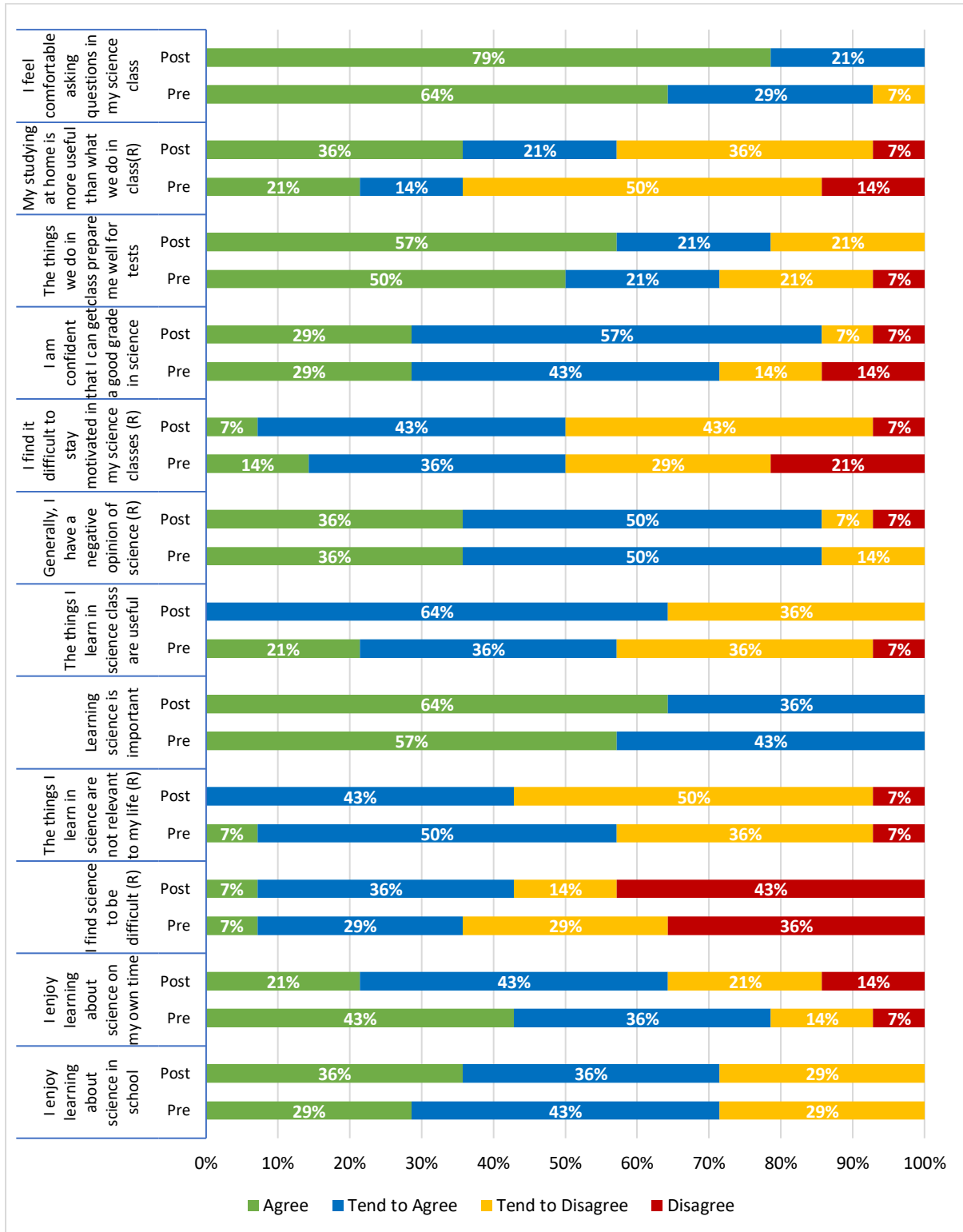


Figure 2. Pre and posttreatment Likert-style survey responses. (R) indicates reversed scores for negative statements, ($n=14$)

The Likert style questions that appeared on both surveys were split into four categories, each containing three questions. The first category of questions related to how much the students liked science as a subject, the second was related to how applicable the students felt the course material was to their lives, the third was related to the difficulty of the course material, and the fourth related to their attitude/motivation in class. The scores for the questions within each category were added together for a maximum value of 12. A combined score of 6 or lower was considered negative, a score of 7 or 8 was considered neutral, and a score of 9 or higher was considered positive (Figure 3). While there were some slight differences between the pre and post treatment scores, a Chi squared analysis did not show any of the differences to be statistically significant.

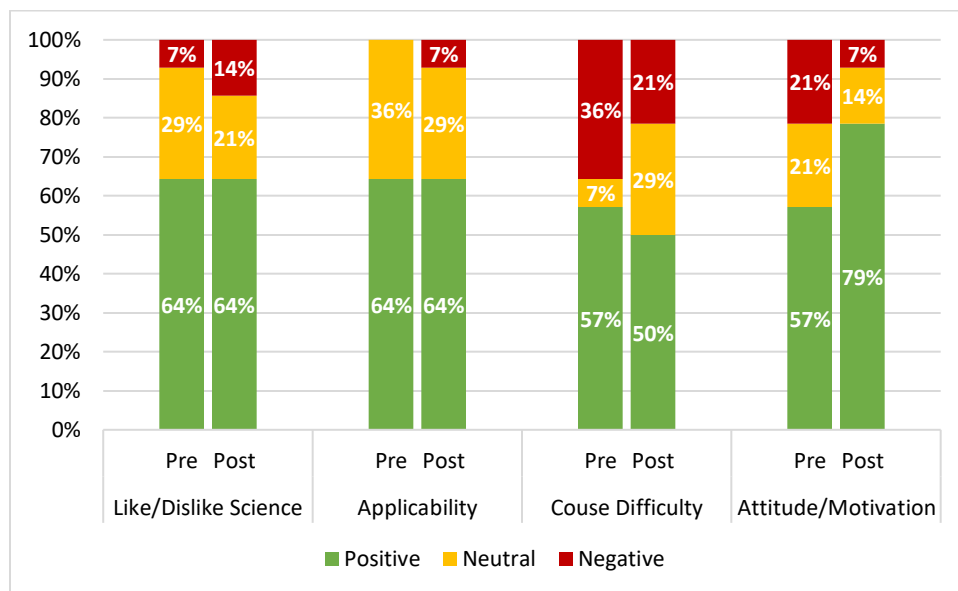


Figure 3. Pre and posttreatment student responses to Likert question categories, ($n=14$)

There were five Likert style survey questions that only appeared on the posttreatment survey. They were aimed at gathering data on student feelings surrounding the Muddiest Point (MP) and Applications Cards (AC) activities (Figure 4). The only question that more than half of

the participants agreed or tended to agree with was I found the Muddiest Point activity to be useful. Less than half the class found the AC to be useful, and there is not a strong indication that the class as a whole thought either activity helped them to score better on tests. The portion of students who felt the MP and AC helped them to score better on tests were 50% and 43% respectively.

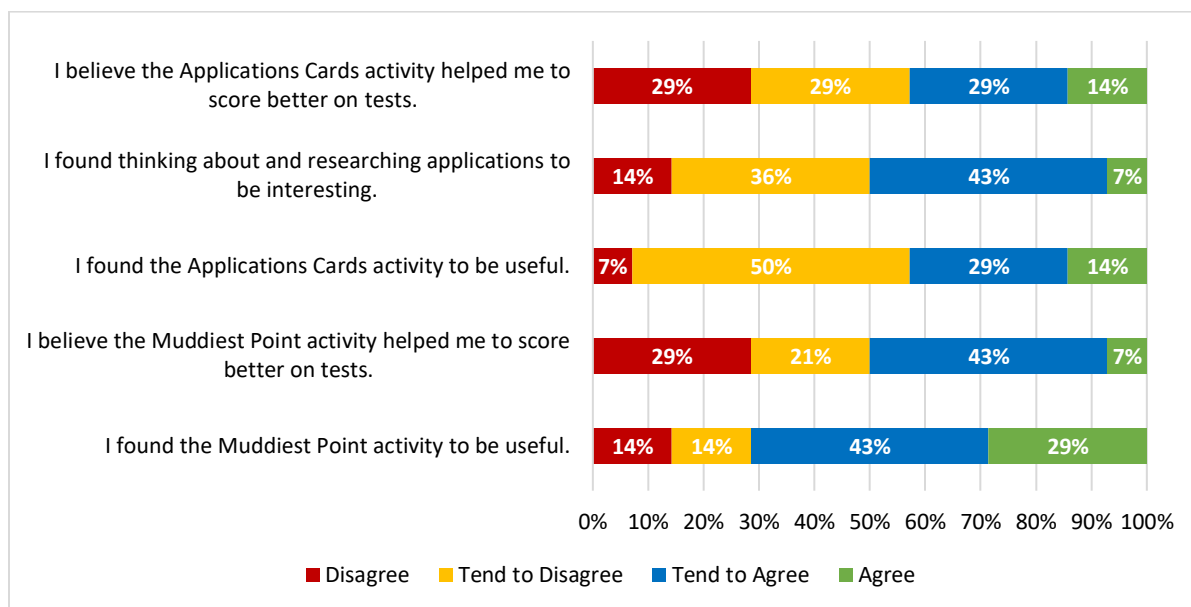


Figure 4. Likert style questions exclusive to posttreatment survey, ($n=14$).

The open-ended questions on the posttreatment survey gave students the opportunity to voice their opinions about the MP and AC activities. Many students gave short responses without much content, but a few students articulated what they found to be useful about the Muddiest Point. One student wrote, “You kind of take a step back and realized what we are learning about.” Another simply stated, “Muddiest point was useful.”

The final data collection instrument used was a posttreatment group interview. The interview was voluntary, and participation was very low, but the two who did participate had

some interesting things to say. When asked how they felt about the MP activity, the students seemed to agree that it felt like it could be useful in some circumstances. The students who chose to participate also happened to be high-performing students, so they did not feel that they had personally needed the activity to succeed. One student said, “I do think, overall, the Muddiest Point is something good to be added to the class for everyone really. I think it does benefit me if there’s something that I didn’t completely get.” When asked about their experiences with the AC activity, the students said that they found it interesting, and they enjoyed thinking about the real-world applications of the things they learned in class. However, students agreed that they didn’t think it would be as useful or enjoyable for students that were struggling to understand the material in the first place. When asked whether they thought the AC made learning the material easier, they said that it did not generally make it easier to learn the concepts, but they could see how understanding the real-world applications could theoretically be helpful.

CHAPTER FIVE

VALUE: REASONING AND REFLECTION

Claims from the Study

The results of this study were inconclusive as to the impact of the combined use of Muddiest Point (MP) and Applications Cards (AC) formative assessment techniques in a high Introductory Physical Science course. There was no increase in normalized gains on pre and posttests between the nontreatment unit and the treatment unit. Paired t-tests showed that the change in normalized gains was not statistically significant. The p value was greater than .05. Analysis did, however, show a statistically significant correlation ($p = .002$) between student's normalized gains in the two units. Individual students were likely to have similar gains in the nontreatment and treatment units. This indicates that students who struggled with the material did not gain much in terms of performance from MP and AC activities. Higher achieving students remained high achievers, but because there is an upper limit on normalized gains, it is difficult to say how much, if at all, they gained from the treatment.

While most of the survey results were also inconclusive, I can make the claim that the majority of students found the MP to be useful. Chi squared analysis did not show a significant difference between the responses to the pre and posttreatment questions that appeared on both surveys. The additional questions that were on the posttreatment survey revealed that 72% of respondents agreed or tended to agree that the MP was useful. That being said, only 50% agreed or tended to agree that the MP helped to increase their scores on assessments. While the students may have thought that MP was useful, I cannot make the claim that MP actually increased their

scores. I suspect this may be due, in part, to the disparity in difficulty between the units and the limited timeframe under which this study took place.

The posttreatment interviews showed that the students who participated in the interviews saw the potential benefits of MP and AC, but they didn't indicate that they had personally gained anything from them. I found it interesting to hear the students' opinions about the activities, and their opinions were generally positive. The interviewed students represent a small portion of the class, and their views may or may not align with the class as a whole. Because participation was entirely voluntary, I had little to no control over who participated. All of the students who volunteered to be interviewed were high-performing students who seemed to have an inherent interest in the course material.

Value of the Study and Consideration for Future Research

While the results of this study were inconclusive, I believe that I learned things from this study that may help me to more successfully carry out future research. There were a number of factors that I believe made it difficult to set up and carry out this study in a way that would yield significant results. While it is possible that MP and AC are not actually effective tools to improve student performance or attitude, the studies outlined in my conceptual framework present a strong argument that they can be. Muteti et al. (2022) and Oguguo et al. (2025) both found significant improvements in student performance through the implementation of MP, and Srisky et al. (2023) found significant improvement in both student performance and perception of course content relevance through the implementation of AC. I suspect that if I could have changed a few components of my research, I may have had different results.

I work at a small school with small sample class sizes. Ideally, I would have had a nontreatment group and a treatment group that were covering the same material in class, but because of my small class sizes, it would have been unlikely that I could have gotten any significant results with such small sample sizes. Instead, I used a nontreatment and treatment unit that did not cover the same material. This allowed me to have bigger sample sizes, but it introduced variability in the difficulty of the material between the nontreatment and treatment units. In my experience, Unit 4 (treatment unit) tends to be more difficult for most students than Unit 3 (nontreatment unit), which is not ideal. Because I was constrained as to what time of year I carried out my research, and I was not able to logically reorder that material in my course, I did not have the freedom to remedy this issue.

Because I could not run the treatment and nontreatment groups concurrently, I also had limited time to apply the treatment. This was also intensified by a number of snow days that fell during the treatment unit. Based on their responses, I believe that some students did not have enough time or repetitions with the MP and AC. It seemed that they did not quite understand the instructions or the idea of the activities. For example, in their responses to the AC prompt, a number of students said a real-world application of the material was that they would now know how to do it if they study science in college. While this might be true, it is not the kind of response I was asking for. The small number of repetitions was especially present for the AC. Though they were a required assignment, many students neglected to complete them at least once. Student responses indicated that they had a better understanding of the MP and that they found them to be useful. This makes me inclined to continue the use of MP in the future to see if I start to see student improvements.

If I were to carry out further research on this topic, I would design my study in a way to avoid these pitfalls. Firstly, I would try to pick treatment and nontreatment units that had more parity in difficulty. I would also plan to carry out the research over a longer period of time. If students had more time to understand and get used to MP and AC, I may get a higher rate of participation and more in-depth responses. Based on the evidence from previous studies and my students' interview responses indicating that they saw the potential benefits of MP and AC, I do think further research would be warranted. Once I determined how to carry them out, the implementation of MP and AC required very little additional time, so carrying out further research would be a minimal burden as an instructor.

Impact of Action Research on the Author

While my results may not have been statistically significant, I did learn some valuable lessons from my research. As a relatively new teacher, I do not have much experience experimenting with new techniques in my classroom. The Action Research tools I have gained from carrying out this study have empowered me to make adjustments in my classroom and more objectively scrutinize their impacts on my students (Mertler, 2016). I now feel more comfortable developing and carrying out a research plan, collecting useful data, and analyzing that data. From this study in particular, I have found that I can still gain valuable insights even when my research does not yield the results that I hope for. My students told me that they found MP to be useful, so I intend to use that activity more extensively in the future to see if more time spent with it has an impact. I still believe that introducing more real-world context to the classroom would be beneficial, so I will try to find new ways to do that. I may modify the AC activity that I did here or develop something new. I suspect that I will start carrying out more

surveys in my classrooms in order to gain a clearer picture of where my students are in terms of their understanding of and attitude toward the material. Overall, I feel that I have grown as a teacher through the process of Action Research, and I am hopeful that my students will benefit from that in the future.

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APPENDICES

APPENDIX A: IRB EXEMPTION

Protocol Information

General Info

Reviews

E-Signatures

Emails

Protocol Active?

☒

Protocol #

2026

2390

EXEMPT

Version #

1

Reference Number

2390

PI

Glenn, Edwin

Protocol Type

Original

Status

Approved

Changed By Staff

Szott, Brenna

Form Name

IRB Exempt Research Form v6

Created

11/25/2025 3:14 PM

Last Updated

1/28/2026 10:31 AM

Submitted

1/27/2026 9:18 AM

Inactive Date

Approved

1/28/2026

Effective

1/28/2026

Next Review

1/28/2031

Renewal

1/28/2031

Expires

1/28/2031

Figure 5. IRB approval

APPENDIX B: UNIT 3 PRETEST

Unit 3 Pretest

Part 1. Multiple Choice. Circle the best answer for each question. (1 point each)

1. How many electrons can fit in the s orbital of a given energy level?
 - a. 2
 - b. 6
 - c. 10
 - d. 14
2. How many electrons can fit in a set of f orbitals in a given energy level?
 - a. 2
 - b. 6
 - c. 10
 - d. 14
3. How many electrons can fit in a set of d orbitals in a given energy level?
 - a. 2
 - b. 6
 - c. 10
 - d. 14
4. How many electrons can fit in a set of p orbitals in a given energy level?
 - a. 2
 - b. 6
 - c. 10
 - d. 14
5. Which of the following orbitals would fill with electrons first?
 - a. 4s
 - b. 4p
 - c. 4d
 - d. 3d
6. How many electrons can exist in the **1st energy level**?
 - a. 2
 - b. 4
 - c. 8
 - d. 10
7. How many electrons can exist in the **3rd energy level**?
 - a. 6
 - b. 18
 - c. 24
 - d. 32

8. What is the name of the **Group 1A** (1) elements on the periodic table?
 - a. Halogens
 - b. Noble Gases
 - c. Alkaline Earth Metals
 - d. Alkali Metals
9. What is the name of the **Group 2A** (2) elements on the periodic table?
 - a. Halogens
 - b. Noble Gases
 - c. Alkaline Earth Metals
 - d. Alkali Metals
10. What is the name of the **Group 7A** (17) elements on the periodic table?
 - a. Halogens
 - b. Noble Gases
 - c. Alkaline Earth Metals
 - d. Alkali Metals
11. What is the name of the **Group 8A** (18) elements on the periodic table?
 - a. Halogens
 - b. Noble Gases
 - c. Alkaline Earth Metals
 - d. Alkali Metals
12. How many valence electrons does each element in the **Boron Family** have?
 - a. 2
 - b. 3
 - c. 4
 - d. 13
13. How many valence electrons does each element in the **Nitrogen Family** have?
 - a. 2
 - b. 3
 - c. 5
 - d. 7
14. What is a valence electron?
 - a. An electron that has been removed from an atom
 - b. An electron in the highest energy level of an atom
 - c. An electron in the lowest energy level of an atom
 - d. An electron with a positive charge

15. Which of the following is the correct electron configuration for iron (Fe)?
- $1s^2 2s^8 3s^8 4s^8$
 - $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 4d^6$
 - $1s^2 2s^2 2d^6 3s^2 3d^6 4s^2 3p^6$
 - $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$
16. Which of the following is the correct electron configuration for iodine (I)?
- $[\text{Kr}] 5s^2 4d^{10} 5p^5$
 - $[\text{In}] 5p^4$
 - $[\text{Kr}] 1s^2 2d^{10} 3p^5$
 - $[\text{Xe}] 5s^2 4d^{10} 5p^5$
17. What is the average atomic mass of a sample of strontium (Sr) with the following composition?
- $^{86}_{38}\text{Sr}$; 10.42%
 - $^{87}_{38}\text{Sr}$; 7.00%
 - $^{88}_{38}\text{Sr}$; 82.58%
- 3970 amu
 - 0.0202 amu
 - 142 amu
 - 87.7 amu
18. What is the average atomic mass of a sample of strontium (Sr) with the following composition?
- Ru-100; 1.15%
 - Ru-101; 86.98%
 - Ru-102; 11.87%
- 33.70 amu
 - 101.11 amu
 - 134.33 amu
 - 111.46 amu

APPENDIX C: UNIT 3 POSTTEST

Unit 3 Posttest

Part 1. Multiple Choice. Circle the best answer for each question. (1 point each)

1. The mass of a neutron is _____ the mass of an electron?
 - a. about the same as
 - b. much larger than
 - c. much smaller than
 - d. randomly larger or smaller than
 - e. one half of
 - f. twice
2. Which subatomic particles are located outside the nucleus of the atom?
 - a. Electron
 - b. Neutron
 - c. Proton
 - d. a and b
 - e. b and c
 - f. a, b, and c
3. Which of the following orbitals would fill with electrons first?
 - a. 4s
 - b. 4p
 - c. 4d
 - d. 3d
4. How many electrons can exist in the **2nd energy level**?
 - a. 2
 - b. 4
 - c. 8
 - d. 10
5. How many electrons can exist in the **4th energy level**?
 - a. 6
 - b. 18
 - c. 24
 - d. 32
6. For a given energy level, what is the max number of electrons that can exist in the **d orbitals**?
 - a. 10
 - b. 18
 - c. 32
 - d. 50
7. What is the name of the **Group 1A** (1) elements on the periodic table?
 - a. Halogens
 - b. Noble Gases
 - c. Alkaline Earth Metals
 - d. Alkali Metals

8. What is the name of the **Group 2A** (2) elements on the periodic table?
 - a. Halogens
 - b. Noble Gases
 - c. Alkaline Earth Metals
 - d. Alkali Metals
9. What is the name of the **Group 7A** (17) elements on the periodic table?
 - a. Halogens
 - b. Noble Gases
 - c. Alkaline Earth Metals
 - d. Alkali Metals
10. What is the name of the **Group 8A** (18) elements on the periodic table?
 - a. Halogens
 - b. Noble Gases
 - c. Alkaline Earth Metals
 - d. Alkali Metals
11. How many valence electrons does each element in the **Boron Family** have?
 - a. 2
 - b. 3
 - c. 5
 - d. 7
12. What does the atomic number of an element represent?
 - a. The number of protons in its atoms
 - b. The number of electrons in its atoms
 - c. The number of neutrons in its atoms
 - d. The sum of the protons and neutrons in each of its atoms
13. How many protons are in one atom of ${}^{59}_{27}\text{Co}$?
 - a. 27
 - b. 59
 - c. 32
 - d. 86
14. How many neutrons are in one atom of Germanium-73?
 - a. 32
 - b. 73
 - c. 41
 - d. 105
15. How many electrons are in one neutral atom of ${}^{182}_{73}\text{Ta}$?
 - a. 73
 - b. 182
 - c. 109
 - d. 255

16. Which of the following is the correct electron configuration for silver (Ag)?
- $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 4d^{10} 4p^6 5s^2 5d^9$
 - $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^9$
 - $1s^2 2s^8 3s^8 4s^{18} 5s^{11}$
 - $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^9$
17. Which of the following is the correct electron configuration for niobium (Nb)?
- $[\text{Rb}] 5s^2 4d^3$
 - $[\text{Rb}] 5s^1 4d^3$
 - $[\text{Kr}] 1s^2 2d^3$
 - $[\text{Kr}] 5s^2 4d^3$
18. What is the average atomic mass of a sample of oxygen (O) with the following composition?
- 99.76% oxygen-16
 - 0.0400% oxygen-17
 - 0.200% oxygen-18
- 1570 amu
 - 0.00391 amu
 - 20.24 amu
 - 16.00 amu

APPENDIX D: UNIT 4 PRETEST

Unit 4 Pretest

Circle the best answer for each question. (1 point each)

1. An atom with a net positive (+) charge is called...
 - a. a molecule
 - b. an anion
 - c. a cation
 - d. a polyatomic ion
2. A halogen will become which type of ion?
 - a. anion
 - b. cation
3. The amount of energy released when an electron is added to a neutral atom is...
 - a. electron affinity
 - b. electronegativity
 - c. ionization energy
 - d. atomic radius
4. The atomic radius of a magnesium atom is ____ than that of a sodium atom.
 - a. larger
 - b. smaller
5. The ionization energy of a phosphorus atom is ____ than that of a sodium atom.
 - a. larger
 - b. smaller
6. The electron affinity of a phosphorus atom is ____ than that of a sodium atom.
 - a. larger
 - b. smaller
7. The electronegativity of a phosphorus atom is ____ than that of a sodium atom.
 - a. higher
 - b. lower
8. ____ bonds are chemical bonds in which electrons are shared.
 - a. Ionic
 - b. Covalent
9. In a molecule with a polar covalent bond, the element with the lower electronegativity will be...
 - a. an anion
 - b. a cation
 - c. partially positive
 - d. partially negative
10. A molecule is...
 - a. a neutral group of atoms that is joined together by covalent bonds
 - b. a group of ions held together by ionic bonds
 - c. a and b
 - d. none of the above

11. Choose the correct name for this compound: **NiP**

- a. Nickel monophosphide
- b. Nickel phosphate
- c. Nickel(III) phosphide
- d. Mononickel monophosphate

12. Choose the correct name for this compound: **C₃N₄**

- a. Tricarbon tetranitride
- b. Carbon(III) nitride(IV)
- c. Carbon nitride
- d. Tricarbon quadnitride

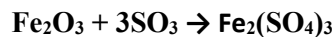
13. Choose the formula for this compound: **Magnesium chloride**

- a. MgCl
- b. MgCl₂
- c. Mg₂Cl
- d. Mg₂Cl₂

14. Choose the formula for this compound: **Iodine heptafluoride**

- a. IF
- b. I₄F₄
- c. IF₆
- d. IF₇

15. Consider the reaction below. If 12.5 g of Fe₂O₃ were allowed to react with excess SO₃, how many grams of Fe₂(SO₄)₃ would be produced?



- a. 10.4 g
- b. 12.5 g
- c. 31.3 g
- d. 50.0 g

APPENDIX E: UNIT 4 POSTTEST

Unit 4 Posttest

Circle the best answer for each question. (1 point each)

1. An atom with a net negative (-) charge is called...
 - a. a molecule
 - b. an anion
 - c. a cation
 - d. a polyatomic ion
2. An alkali metal will become which type of ion?
 - a. anion
 - b. cation
3. The tendency of an atom to attract electrons toward itself is...
 - a. electron affinity
 - b. electronegativity
 - c. ionization energy
 - d. atomic radius
4. The amount of energy required to remove an electron from an atom is...
 - a. electron affinity
 - b. electronegativity
 - c. ionization energy
 - d. atomic radius
5. The atomic radius of a lithium atom is ____ than that of a potassium atom.
 - a. larger
 - b. smaller
6. The ionization energy of a lithium atom is ____ than that of a potassium atom.
 - a. larger
 - b. smaller
7. The electron affinity of a lithium atom is ____ than that of a potassium atom.
 - a. larger
 - b. smaller
8. ____ bonds are chemical bonds in which electrons are transferred.
 - a. Ionic
 - b. Covalent
9. In a molecule with a polar bond, the element with the higher electronegativity will be...
 - a. an anion
 - b. a cation
 - c. partially positive
 - d. partially negative

10. Which of the following is one of the diatomic elements?
- Boron
 - Beryllium
 - Bismuth
 - Bromine
11. Choose the correct name for this compound: Se_2Cl_5
- Selenium chloride
 - Biselenide tetrachloride
 - Selenium(II) chloride
 - Diselenium pentachloride
12. Choose the correct name for this compound: Cu_3N
- Copper(I) nitride
 - Copper(III) nitride
 - Tricopper mononitride
 - Tricopper nitrate
13. Choose the formula for this compound: **Vanadium(III) oxide**
- VO_3
 - V_3O
 - V_3O_2
 - V_2O_3
14. Choose the formula for this compound: **Silicon heptabromide**
- SiBr_7
 - SiBr_6
 - Si_7Br
 - Si_6Br
15. Consider the reaction below. If 6.75 g of SO_3 were allowed to react with excess Fe_2O_3 , how many grams of $\text{Fe}_2(\text{SO}_4)_3$ would be produced?
- $$\text{Fe}_2\text{O}_3 + 3\text{SO}_3 \rightarrow \text{Fe}_2(\text{SO}_4)_3$$
- 0.450 g
 - 2.25 g
 - 11.2 g
 - 20.3 g

APPENDIX F: PRE AND POSTTREATMENT SURVEYS

Please indicate the level to which you agree with the following statements:

1. I enjoy learning about science in school.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
2. I enjoy learning about science on my own time.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
3. I find science to be difficult.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
4. The things I learn in science are not relevant to my life.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
5. Learning science is important.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
6. The things I learn in science class are useful.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
7. Generally, I have a negative opinion of science.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
8. I find it difficult to stay motivated in my science classes.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree

9. I am confident that I can get good grades in science.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
10. The things we do in class prepare me well for tests.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
11. My studying at home is more useful than what we do in class.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
12. I feel comfortable asking questions in my science class.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
13. Do you have any comments about the applicability of your science class to your real life?
14. Do you have any comments about the difficulty of your science class?

QUESTIONS ONLY ON THE POST-TREATMENT SURVEY

1. I found the Muddiest Point activity to be useful.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
2. Please elaborate. What did you find useful or not useful about it?
3. I believe the Muddiest Point activity helped me to score better on tests.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree
4. Do you have any other comments about the Muddiest Point activity?

5. I found the Applications Cards activity to be useful.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree

6. Please elaborate. What did you find useful or not useful about it?

7. I found thinking about and researching applications to be interesting.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree

8. I believe the Applications Cards activity helped me to score better on tests.
 - a. Disagree
 - b. Tend to disagree
 - c. Tend to agree
 - d. Agree

Do you have any other comments about the Applications Cards activity?

APPENDIX E: INTERVIEW QUESTIONS

Post Treatment Interview Questions

1. How did you feel about the Muddiest Point exercise?
2. Do you think it made learning the material easier?
3. Did it have an impact on how comfortable you felt asking questions during class?
4. Is there anything else you would like me to know about your experience with Muddiest Point?
5. How did you feel about the Applications Cards exercise?
6. Do you think it made learning the material easier?
7. Did it have an impact on how relevant you felt the material was to your life?
8. Is there anything else you would like me to know about your experience with Applications Cards?