

BRIDGING THE GAP BETWEEN MATH AND SCIENCE: DOES THE USE OF SIMPLE
MATH INSTRUCTION TOOLS PRODUCE GROWTH IN THE
PHYSICAL SCIENCE CLASSROOM?

by

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DEDICATION

This is dedicated to my father, Patrick Doyle, who taught me the value of hard work and the importance of education. I miss you Dad, and I wish you were here to see this.

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ABSTRACT

It was observed that students struggle with making connections between math and science, especially in a physical science class. Research shows that this is not a behavioral issue, but a cognitive one. This is very problematic because it has been shown that making cross curricular connections is the foundation to critical thinking, and critical thinking is a highly desired skill in any field of study or career. As a potential solution to this problem, three treatments were administered to two different advanced physical science classes with two different trials. The treatments included math warm-ups at the start of a lesson, scaffolded guided practice problems at the conclusion of a lesson, and the use of graphic organizers when new formulas were introduced. Most students claimed the treatments were helpful, and there was growth in students' assessment scores.

BACKGROUND AND INTRODUCTION

Grand Valley High School is a public 9-12 high school located in the town of Parachute, in western Garfield County, on the western slope of Colorado. Oil and natural gas production and development is the primary industry in Parachute. Since the industry hinges on market prices, the town has boom and bust cycles. This also results in a large itinerant population. Thus, only a small number of students have completed the entire K-12 system in our district. Residents that are not involved in the oil and gas industry, work skilled trades, or are general laborers, and typically commute to the Roaring Fork Valley, which is an extremely high socioeconomic community, about 30 miles away. We are considered a rural school with a student population of 329 students. Roughly 45% of our students receive free and reduced lunch (Finn, 2019). Grand Valley has a 40% population of students who are not of Caucasian heritage (Finn, 2019). This school follows a standards-based philosophy with their grading systems, has a reputation for being innovative, and has a goal to do their best to prepare graduates for life after high school. As a traditional 9-12 public high school, all teachers, and administrators value the needs of the individual student, and strive to accommodate all learners.

For the last seven years, I have been a full-time science teacher at Grand Valley High School. I have taught Environmental Science, Biology, General Chemistry, Advanced Placement (AP) Chemistry, General Physics, and Algebra-based AP Physics 1. Currently, my teaching assignments are AP Chemistry, Algebra-based AP Physics 1, Introduction to Physics and Chemistry (IPC), and General Biology. My expectation is

that all my students can solve science-related math problems, interpret data from inquiry style labs, and scientifically document their results. These expectations demonstrate what I believe, is necessary for students to attain a deeper understanding of scientific concepts, and they are included in the Colorado Academic Standards (CAS). The Colorado Department of Education (CDE) presents the CAS standards to prepare graduates to grasp and understand science statements, evidence outcomes, and science and engineering practices (Colorado Department of Education, 2020). These skills are also included in the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013).

When I started my teaching at Grand Valley, I was fresh out of an accelerated post undergraduate education program and had finished an entire calendar school year of student teaching. I hold a Bachelor of Science degree in biology, but I was charged with teaching the physical sciences. Within a few weeks, I was shocked at how students struggled with the math components of the physical sciences. As the material got more challenging and complex, the more the students struggled. The biggest red-flag I had that year, was a conversation with a student who was struggling to solve a specific heat calculation in an AP Chemistry class. This young lady was intelligent, enrolled in a pre-calculus math course, and was truly struggling with solving a simple, single-variable formula. Sitting with her, I clearly remember asking her about her math skills. Initially thinking that maybe she was placed in the wrong class, I did some investigating into her math background, because I was rather confused about how she could possibly be struggling. She was currently enrolled in a pre-calculus course, and her teacher said she was finding great success with the coursework. It was not until I had the idea of rewriting

the formula where I changed the variable from “ ΔT ” to “ x ” that she immediately was able to solve the problem. At first, I thought this incident was just an outlier, but years later I found myself coaching students with their math abilities. This does not apply to all students, but even a student who you would consider high level, is struggling, using the skills their math teachers have instilled in them.

The purpose of this study was to find effective strategies to help students who struggle with the application of math in the science classroom. The primary research question for this study was: How does the implementation of simple math instruction tools help students in the science classroom to understand higher level science concepts? To answer this question, three components to this question were developed:

1. How does the review of the math skills needed prior to the new material presented help improve the understanding of the new science concept?
2. How does scaffolding more complex science concepts, mixed with math skills, help improve the understanding of the new science concept?
3. How does the implementation of a mathematical graphic organizer help students with making connections between math and science?

CONCEPTUAL FRAMEWORK

Sound math skills are a necessity for anyone who is studying any of the scientific disciplines. The ability to apply mathematical skills is imperative for a student, regardless of what career path they choose. The better equipped a student is with a solid understanding of math, the easier the path to further success in academics and in life

beyond school. Students struggle with the application of math skills in science class, and in return, this inhibits the formation of critical thinking and higher-level science learning. Research has proven that critical thinking is not a naturally developed skill (Zapalska, McCarty, Young-McLean, & White, 2018). The most effective way it can be taught is through carefully constructed scaffolding, where one slowly and progressively makes their way through higher levels of understanding (Zapalska, McCarty, Young-McLean, & White, 2018). This puts a framework in place for the promotion of critical thinking.

One route for development is through a solid education in science and math. Schrer and Beckmann (2014) determined how important math and science are to help a student develop critical thinking skills. A sample of 276,165 students from 41 countries took the Programme International for Student Assessment (PISA) standardized test. A major component of this test is the assessment of critical thinking and problem-solving skills (Organisation for Economic Co-operative and Development, 2018). Using scores from the PISA test, several applications of statistical analysis were applied. It was found that there is an overlap between mastery of problem-solving and critical thinking skills, and math and science literacy. Data from the Schrer and Beckmann study (2014) introduced the concept of math-science coherence. This concept shows the overlap of math and science skills. The stronger the students math and science skills, the stronger they scored on the problem solving portion of the PISA exam. The data collected from these exams is evidence of science and math literacy do help with the cultivation of critical thinking skills.

The need for students to be critical thinkers in math and science extends beyond the classroom and state-mandated assessments. Universities and perspective employers expect recent high school graduates to have critical thinking skills (Zapalska, McCarty, Young-McLean, & White, 2018). As new career possibilities open up in the future, competency in math and science will be incredibly important for professionals in order to find success. It was noted in a study by Byers-Winston and Fouad (2008) that "... even federal trial judges are required by the U.S. Supreme Court to evaluate whether evidence is sufficiently grounded in scientific principles before admitting it for trial". Many post-secondary engineering, business, and computer science courses focus on problem solving and critical thinking to prepare their graduates for success in their chosen fields (Wismath, 2015). Even in medicine, a typical teaching strategy is to use critical thinking and problem solving to learn the content. But, if the student has weak critical thinking skills, it is extremely hard to learn the content (Wismath, 2015).

It is a necessity for a student to have critical thinking skills. An issue that is faced by science educators is that sometimes there is a disconnect for students between different content areas. Dividing up various content areas allows students an easier time understanding different subjects (Schell & Wicklein, 1995). In the short term, this makes the learning of different subjects a little less complicated. But, students begin to lose sight of the big picture and overarching ideas. Multiple studies have shown that when a science curriculum has been integrated with mathematics, there is a greater increase in the understanding of both subjects and problem-solving (Schrer & Beckmann, 2014). A case study presented by Schell and Wicklein (1995) discussed a situation in a small school in

Colorado County, Texas. An Algebra I, Applied Physics, and Introduction to Engineering course was combined, and instructors from the different disciplines teamed up to teach the course. The instructors alternated days in which they would instruct, with the goal of combining their disciplines to teach students how to problem solve. At the end of the course, one of the major successes was that students were able to make strong connections to the other content areas, and see the applications of the knowledge. Students are frequently unable to transfer their knowledge from one discipline to another, and even between the different sciences. (Lin-Sigler, Ahn, Chen, Fu-Fen, & Lucero, 2016). Many secondary science classrooms only address the “big four”: physics, chemistry, biology, and earth science, without showing any connection between the science subjects. This results in the lessening of the science learning experience and leads to a greater disconnect (Eylon & Linn, 1988).

Critical thinking is only a part of demonstrating mastery in the sciences. Mindset and attitudes in the classroom can make a big difference in how receptive students are to learning a new concept, or in applying new skills to a different content area. Learning math and science go hand in hand. The application of math in the science classroom leads to students understanding the mathematical process and a richer understanding of a scientific phenomenon (Westbrook, 1998). In an instance where a math and science teacher teamed up to teach students about a unit on density, the science teacher focused primarily on the science aspects of the topic and the math teacher focused on the execution of the math and interpretation of graphs. At the end of the unit, not only did

students find success with their studies, they were also able to make very deep connections between the two core subject areas (Westbrook, 1998).

Considering issues students have with cross curricular connections, some schools have recognized those issues and are trying new ways to get students to think beyond specific subjects. An issue with the assembly of cross curricular courses is the actual creation and execution of a successful course. There are three aspects that need to be taken into consideration when a teacher is trying to integrate other subject areas into their course; teachers need to have their instruction data driven and specific, have an understanding of starting competencies of the students, and a strong understanding of the assessment standards. A need for the integration of teaching methods also needs to be included, because a science teacher is not going to be using the same methods as an English language arts teacher. More importantly, there needs to be some sort of theme and process set into the curriculum to show students how the subject areas relate to one another (Davison, Miller, & Metheny, 1995). When all the above strategies are in place and well executed, student motivation and development of abilities will increase (Schrer & Beckmann, 2014).

Another prerequisite to cultivating cross curricular connections in the classroom is a commitment to the activation of student background knowledge. When using background knowledge as a jumping off point for new knowledge, the new knowledge can be incorporated in to a linguistic or non-linguistic representation. In Marzano, Pickering, and Pollock's book *Classroom Instruction that Works* (2001), they point out

that “the more we use both systems of representation, linguistic and nonlinguistic, the better we are able to think and recall knowledge.” An example of a nonlinguistic tool would be the graphic organizer. The purpose of a graphic organizer is to aid in the organization and clarification of thoughts, organize thinking strategies, and find solutions to problems (Zollman, 2009). Using a graphic organizer, not only as an organization tool, also allows students to show if they understand the process that is being taught (Browder, et al., 2018). Graphic organizers can be used across all subject areas and have a wide variety of styles. When you have a student struggling with making connections from background knowledge to new knowledge, it can help students, especially visual learners, to make those connections (Watt, Therrien, Kaldenberg, & Taylor, 2013).

Despite the issues students and teachers have with the integration of cross curricular subjects and accessing background knowledge, we forget that when our students leave our schools and go out into the real world, the challenges they are going to face do not fit into neat and tidy subjects. Real world problems are messy, and combine all the facets of education students receive in our classrooms. In a typical science classroom, under the guise of inquiry, students are only guided into one main idea, and all the other important supporting aspects of the lab or concept are ignored. Rarely are students tasked with a real problem or asked to find real solutions to a problem that they one day will have to tackle as adults (Roth, 1992).

Regardless of what future career and education pursuits, it is important that a student can apply critical thinking skills. An avenue of teaching this is through the

development of math and science skills. Strong math skills are essential to gaining a deep understanding of science, which provides opportunities to develop important critical thinking skills. Science and math are not the only path to critical thinking. Students need to realize that all their subjects are interconnected, even though superficially it may not seem so. Data has suggested that these methods help drive student growth and achievement, and as educators hone their craft, these methods will be used in the public-school classroom.

METHODS

The purpose of my research project was to determine if the use of simple math instruction tools help students in the science classroom understand higher level science concepts.. This study was conducted with AP Chemistry, and AP Physics 1 science courses. The total sample size is 21 ($N=21$) with 11 students from an AP Chemistry course, and 9 students from an AP Physics 1 course. Only 30% of this sample were currently enrolled in an intermediate level algebra course or lower, and 5% were enrolled in AP Calculus BC, the top math class the high school offers. Of this sample, 43% were girls, and 30% of students were of mixed or non-Caucasian descent. All students enrolled in these courses demonstrated high achievement in previous science courses, and most had ambitions of pursuing post-secondary education in the fields of science, engineering, or medicine.

Three different treatments were performed in two trials to help students apply their math skills in a physical science classroom. 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). The end goal was to help students improve their comprehension of physical science. By reviewing math skills prior to learning new information on a science concept, the goal for the first treatment was to have the students focus more on the application of the new physical science concepts instead of worrying about how to perform the mathematics (Appendix D). A scaffolding technique was implemented as a second treatment to build the understanding of basic concepts of the new science material, with the goal of bringing students to the level of understanding needed to find success in an AP program. This was done using guided practice problems, ranging from foundational to higher order thinking (Appendix E). During the introduction of new formulas in the courses, a third treatment, in the form of a graphic organizer, was implemented to help students organize the process of taking problems and applying the concepts and math to solve them (Appendix F). These were given to students during lectures where they were given direct instruction on new material. It was the intention that this would help prevent any intimidation of the new material, and keep students' thoughts organized and focused on applying their new knowledge of the concept, and less on the mechanics of solving the problem.

Twenty-one students from two different advanced placement physical science classes were surveyed (Appendix C) and assessed to establish a baseline of information about participants (Appendix G). Baseline information included current attitudes about math and science, and initial thoughts about proposed treatments. Students were given each treatment explained above, assessed for growth in their learning, and surveyed about

the experience after the trials were completed. The primary research question for this study is: How does the implementation of simple math instruction tools help students in the science classroom to understand higher level science concepts? To answer this question, it was broken down into three sub-questions. Each question had its own treatment to see how effective the prescribed treatment was. Before starting treatment, a survey was given to a sample size of 21 students (Appendix C). Below is the research matrix that was used for this study (Table 1).

Table 1
Research Matrix

	Data Collection Instruments:			
Research Question: How does implementation of simple math instruction tools help students in the science classroom understand higher level science concepts?	Treatment groups will complete entry survey about their partiality towards math and science.	Pre-assessment on science concepts covered in the unit.	Post assessment on science concepts covered in the unit.	Treatment groups will complete exit survey about partiality towards math and science.
Research SQ. 1: How does the review of the math skills needed prior to the new material presented help improve the understanding of the new science concept?	Treatment groups will complete entry survey about their partiality towards math and science	Pre-assessment on science concepts covered in the unit.	Post assessment on science concepts covered in the unit	Treatment groups will complete exit survey about partiality towards math and science.
Research SQ. 2: How does the scaffolding of more complex science concepts mixed with math skills help improve the understanding of the new science concept?	Treatment groups will complete entry survey about their partiality towards math and science	Pre-assessment on science concepts covered in the unit.	. Post assessment on science concepts covered in the unit	Treatment groups will complete exit survey about partiality towards math and science.
Research SQ. 3: How does the implementation of a mathematical graphic organizer help students with making the connections between math and science?	Treatment groups will complete entry survey about their partiality towards math and science	Pre-assessment on science concepts covered in the unit.	Post assessment on science concepts covered in the unit	Treatment groups will complete exit survey about partiality towards math and science.

The sample groups were from two different physical science classes: AP Physics 1, and AP Chemistry, and they ranged in math abilities from Math 3 (a basic algebra course) to AP Calculus BC. The implementation of the pre and post treatment survey was to not only establish a baseline of attitudes about the perspective treatment, but also to gather information about the student's mathematics backgrounds, and how they are currently performing in both science and math class. The data collected from the survey

was a mix of qualitative and quantitative data. The qualitative data went through a thematic analysis process and the data was used to compare to data collected at the end of the treatment. The quantitative data was used to see if there were any connections between math skills and their math grades. Prior to treatment, in addition to a survey, all students were given a pre-assessment to establish a baseline for academic growth. The pre-assessment was used to gauge the student's understandings of background knowledge needed to build skills to gain mastery of the new skills and concepts of the unit. At the end of each trial a post assessment was administered with the original preassessment questions embedded in the assessment. Data collected was entered on a spreadsheet, and the mean, median, mode, and standard deviation of scores were analyzed for each AP physical science course. Once the survey and pre-assessment were administered, the treatments began. A second trial, immediately following the first trial, was conducted using the same treatments. Once both trials were completed, an exit survey covering the same questions was given to students.

The first treatment was to address the first research sub question: How does the review of math skills needed, prior to the new material presented, help improve the understanding of the new science concept? This question was addressed with a simple math warm-up, (Appendix D), on days where a new formula with a concept was introduced. The warm-up's intention was to review the math skills that would be needed for the new material that would be covered for the day. The warm-up was briefly reviewed before the start of the actual lesson.

The second treatment involved a scaffolding strategy that was used to present the new material. Specifically, it was used to answer the second sub-question: How does scaffolding more complex science concepts combined with math skills help improve the understanding of the new science concept? This strategy involved multi-tiered, guided practice problems, that varied in degrees of difficulty, according to the Bloom's Taxonomy scale. The problems scaffolded the student to the level of Bloom's scale that is required for the State of Colorado standard, and College Board standards.

Finally, the third treatment answered the third sub-question: How does the implementation of a mathematical graphic organizer help students with making connections between math and science? Students were given a graphic organizer during the presentation of new learning material (Appendix F). The information recorded in the graphic organizer was given to students in the direct instruction method, with the intention to give students a tool to help organize new information about the formula into manageable pieces.

At the end of the unit, students received a summative assessment that was used to see if there was any significant academic growth, and if so, which groups were affected the most by it. The quantitative data was entered on a spreadsheet, and the mean, median, mode, and standard deviation of scores were analyzed. At the conclusion of the study, students were given a short survey to see if they felt the treatments were helpful, and a thematic analysis was done to see if there were any changes post treatment. All results

were reported out to other science and math teachers, and the administration at Grand Valley High School.

DATA AND ANALYSIS

This study began the week of January 6, 2020 and students had just returned from holiday break. It was within the first days of being back to school student that they were given entry surveys and pre-assessments of the new material that was going to be covered for the unit of study. A second trial, using only pre-assessments was started roughly the first full week of February, and concluded the week of March 9, 2020. This was the end of the third quarter, and approximately one week away from the school's spring break. Quantitative and qualitative data was collected in the form of survey questions using Google Forms. All survey data and assessments were analyzed using Microsoft Excel spreadsheets.

Prior to beginning treatment, a sample size of 21 students ($N=21$) was given an entry survey prior to treatment, and an exit survey after treatment, pertaining to their present level of math they were currently enrolled in, what grade they were earning, if they like math, if they like science, and their feelings regarding the treatments in which they would be participating in (Appendix C). Of this sample, 43% were enrolled in algebra-based AP Physics 1, and 57% were enrolled in AP Chemistry. Looking at the distribution of enrollment of math classes offered at Grand Valley High School (Figure 1), 70% of students were enrolled in a higher-level math course.

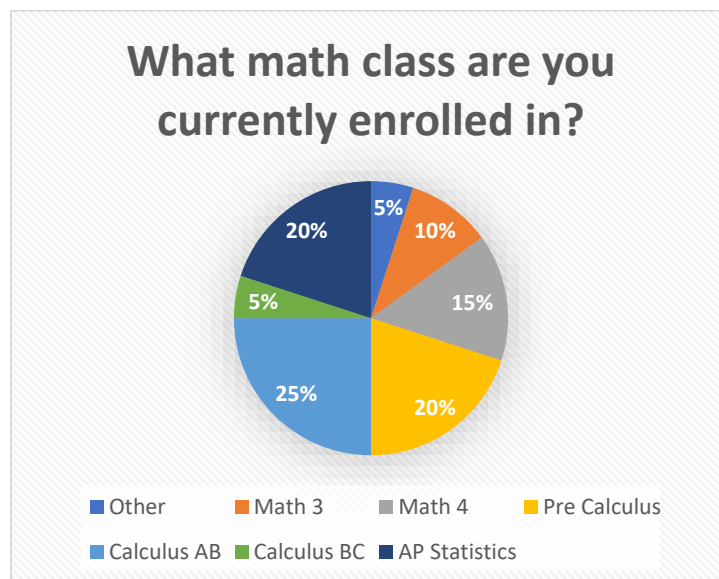


Figure 1. Current math placement of AP Physics 1 and AP Chemistry students, ($N=21$).

When asked in the entry survey about their current grades in their math courses, 57% (Figure 2) reported a grade of three or higher, with no students reporting that they were failing their current math class. In the exit survey, the number of students with a math grade of three or higher had increased to 62%. However, the number of students failing their current math class rose to 19%.

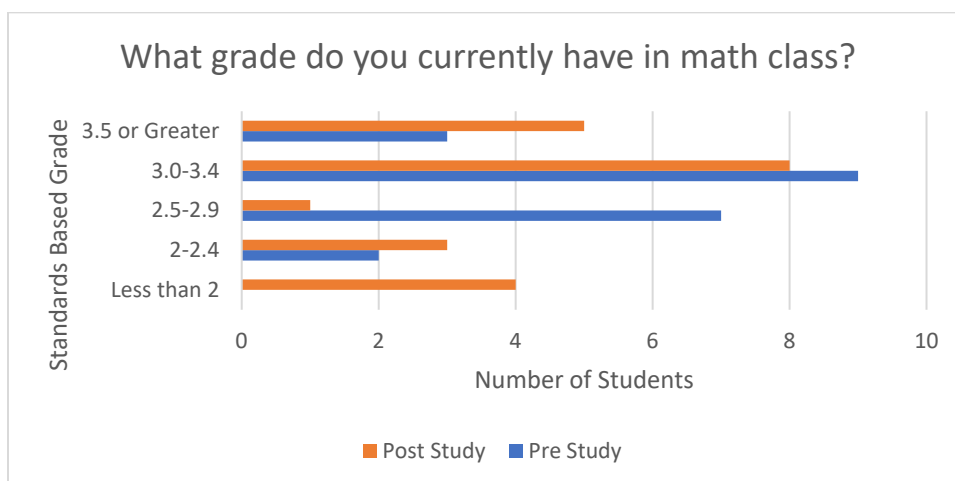


Figure 2. Math grades as reported by students pre and post study, ($N=21$).

A Likert scale, with a rating of 1-5 was used to ask students about their partiality towards math. Sixty percent of students reported their partiality of math as a four or higher, and 20% responded with a two or lower (Figure 3). Students who responded with a 3 or lower were asked to comment on why they rated math with such a low score. Of the seventeen responses with a three or less rating, 53% of students reported that they thought math was too hard, confusing, or they are just bad at it. One student did respond that it, “didn’t interest me and had nothing to do with my career that I want to do.” Another student said, “I hate math but like statistics”. At the end of the treatment, the percentages of student responses about their partiality of math did not change, but the distribution of responses did.

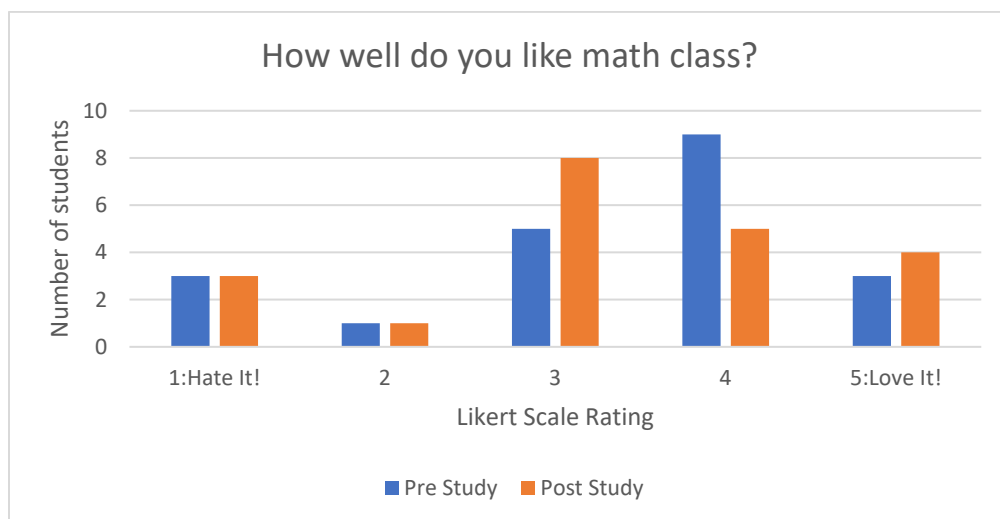


Figure 3. Likert scale of partiality towards math, ($N=21$).

When looking at the grades and partiality towards science, 86% of students had a grade of three or higher pre-treatment, whereas post treatment, 71% of students had a grade of 3 or higher (Figure 4). This study ended one week prior to the end of third

semester. These scores were pulled from a gradebook, and students did not report them out in the survey. No students had failing grades in both pre and post treatment, and in pre-treatment, no students had a grade in the 2-2.4 range; although, post treatment, this rose to 5%.

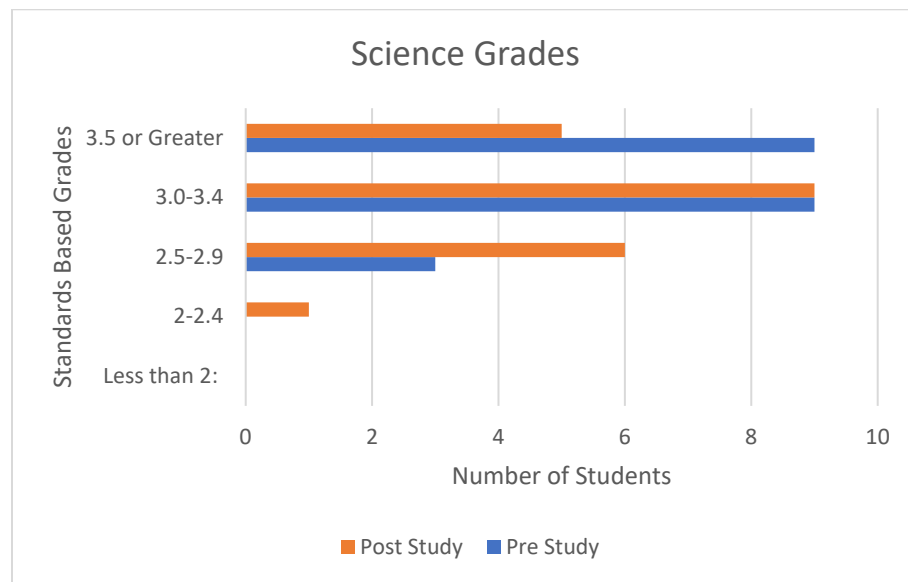


Figure 4. Pre and post study science grades from gradebook, ($N=21$).

Before treatment began, students were surveyed about their partiality toward science. Using a Likert scale to collect data, it was reported that 72% of the students ranked their partiality of science at a four or higher. Only 9% had a partiality of two. At the end of the treatment period, 76% of students ranked their partiality of science as a four or higher, and 14% of students ranked their partiality at two (Figure 5). Students who responded with at three or lower, were asked to comment on why they gave the rating they did. Of that group, 25% said they did not find science interesting, and 45%

said they either did not understand it, or they are bad at it. In both pre and post surveys, no student ranked their partiality of science at a one.

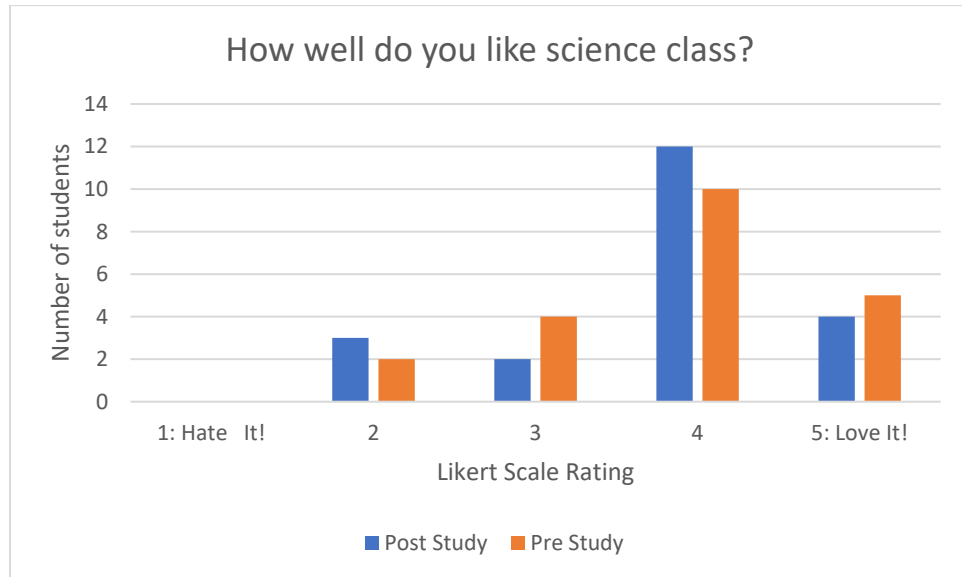


Figure 5. Likert scale ratings of partiality to science, ($N=21$).

Students were asked, pre and post treatment, about the actual treatments during the study. The questions in the pretreatment had students predict if what they were going to be given would be helpful in their learning. The post treatment questions had the same context but were reworded to gauge if they felt the treatment was helpful (Figure 6). In the first question students were asked: “If you were given a very short math warm-up at the start of class that pertained to the physics/chemistry concept you are going to learn about today, do you think it would help you understand the material better? 71% of students responded yes, and 29% felt that it would not be helpful. It was observed that at some point all students working on the warm-ups had questions about how to solve the problems. During this observation, as the math became more and more complex in the warm-ups, even students with higher math skills had some questions about solving them.

The second question proposed was: “If I were to slowly introduce a new chemistry/physics formula to you, do you think it would help you learn the material better?” 81% responded yes to the question, and 19% said no. The last question proposed was: “If you were given a handout to help you organize the solving and analyzing physics/chemistry problems, do you think it would help you learn the material better?” 76% of students responded yes and 24% responded no.

At the end of the two trials, students were asked about their experiences during the study. The first question was: “After working on math warm-ups in class, do you think this helped you understand the material better?” Ninety percent of the student responded yes to this question, and 10% responded no. An optional follow-up question was asked about why they answered yes, or no. One student responded, “My brain has two modes, math mode and not math mode. Sometimes I need a warm-up or a quick review to kick my brain into math mode. The warm-ups help me remember the basic skills I need to use for the new material.” Several students mentioned that it helped get their minds into a math/science mindset, while others appreciated the review of material that they have not seen in a while. A student who responded no said, “I did not feel any more prepared after the warmups”. The second question was: “After working on problems that build on one another, do you think this helped you understand the material better?” Eighty-six percent of students responded yes to this question, and 14% responded no. An optional follow-up question was asked about why they answered yes, or no. Quite a few students answered that it helped reinforce the concepts. One student answered, “I became more lost when I didn’t understand the original problem.” Even

with scaffolding in place, it was observed that a few students struggled greatly with moving onto the more challenging problems. The third question was: “You were given a handout to help you organize the solving and analyzing of physics/chemistry problems. Do you think this helped you learn the material better?” Eighty-six percent of the students said yes, and 14% said no. It was observed that quite a few students used the graphic organizer when working through the guided practice that was provided. An optional follow-up question was asked about why they answered yes, or no. All the responses were in support of those who answered yes. Five students answered that it helped keep them organized when learning the new concept. One student answered, “It gave me a guide that I can look at when I am confused”.

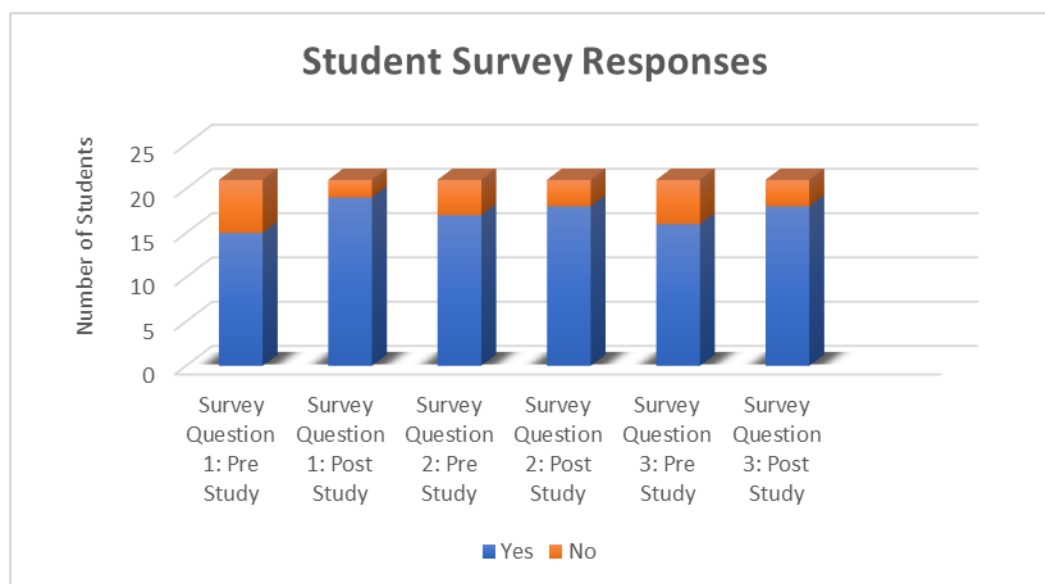


Figure 6. Pre and post study student responses, ($N=21$).

During this study two trials were conducted. Each trial included all three treatments. Prior to the start of each trial, students were given a pre-assessment to determine where they were at in their knowledge on the topic. The science subjects were divided into two groups: the AP Chemistry group, and the AP Physics 1 group. During

the first trial, the AP Chemistry group ($N=12$), had a mean pre-assessment score of 3.92, and a mean post assessment score of 9.73. There was a total of fourteen points available to earn from the assessments. But, it should be noted that there were additional problems added to the post assessment. The additional problems were not considered when comparing pre and post assessment data. There was a mean gain of 5.3 points for the first trial. The median pre-assessment score was 4.00, and median post assessment score was 9.00. The pre-assessment mode was 4.00, and the post assessment mode was 6.00. The standard deviation for the pre-assessment was 2.11, and the standard deviation for the post assessment was 2.37. The second trial had a mean pre-assessment score of 5.83, and a mean post assessment score of 11.33. There was a mean gain of 5.5 points for the second trial. The median score for the pre-assessment was 6.00 and had a median score of 11.50 for the post assessment. The mode for the pre-assessment was 6.00 and 12.00 for the post assessment (Figure 7). Standard deviation for the pre-assessment was 1.11, and 1.61 for the post assessment. A paired students t-test was conducted, and there were no statistical differences between the pre and post assessment for each trial.

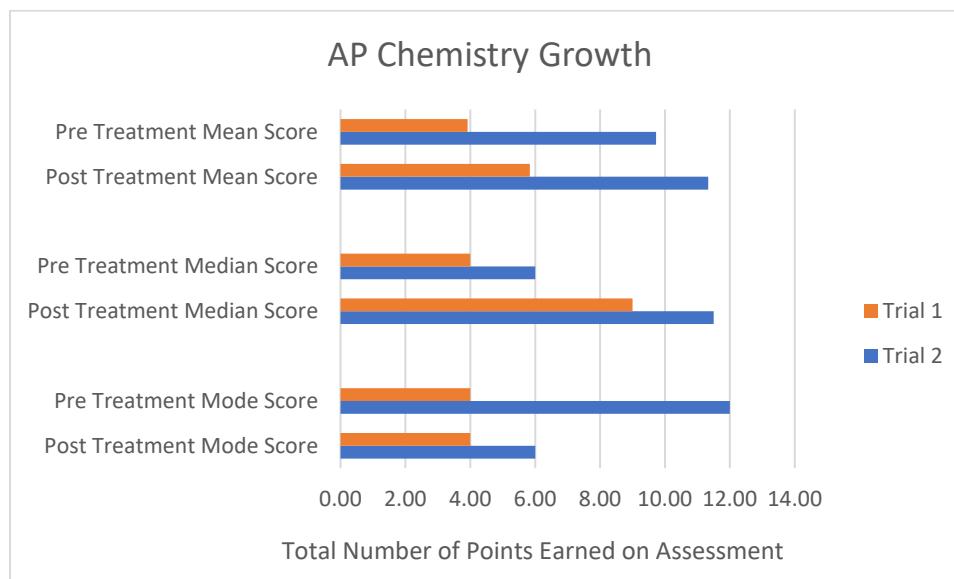


Figure 7. Mean, median, and mode scores for AP Chemistry trials, ($N=12$).

The AP Physics 1 group ($N=9$), for the first trial, had a mean pre-assessment score of 2.44 and a mean post assessment score of 6.00. There was a mean increase in scores of 3.5 points. It should be noted that the post assessment had additional problems that students had not seen in the pre-assessment. Those additional questions were not considered when comparing the pre and post assessment scores. The median pre-assessment score was 3.00 and had a post assessment score of 6.00. The pre-assessment mode was 3.00 and the post assessment score was 5.00. The standard deviation of the pre-assessment was .73, and the post standard deviation score was 1.32. For the second trial, the mean pre-assessment score was 4.00, and the post assessment mean score was 7.11. There was a mean gain of 3.1 points. The median pre-assessment score was 4.00, and the post assessment score was 8.00. The mode for the pre-assessment was 4.00, and the post assessment mode was 5.00 (Figure 8). The standard deviation for the pre-assessment was 1.50, and the standard deviation for the post assessment was 3.02. A

paired students t-test was conducted, and there were no statistical differences between the pre and post assessment for each trial.

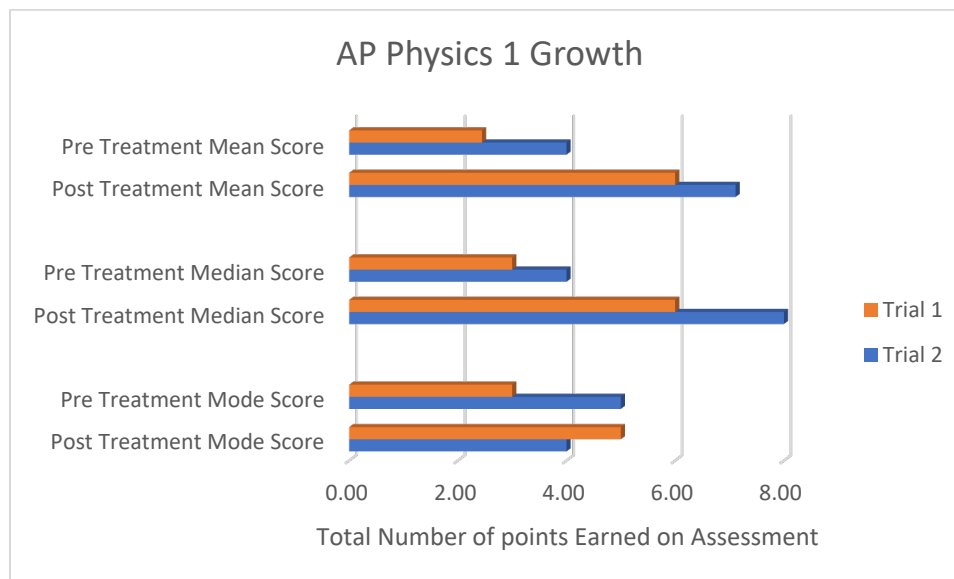


Figure 8. AP Physics 1 mean, median, and mode scores, ($N=9$).

Working through three different treatments, there was an increase in math scores, but no major shifts in the students' attitudes towards math. There was a 15% decrease in overall student science scores, but there was a 4% increase in the students' attitudes towards science. Most of the students who responded unfavorably to their interest in science, claimed to not understand or thought they were bad at it. Their distaste for the subject was also reflected in their grades and growth in the subject. Examining assessment data only, there was at least a 5-point gain in scores for the AP Chemistry course, and at least a 3-point gain for AP Physics 1 scores. Students' responses to the helpfulness of the treatments with their learning were overall positive. The first treatment had a 19% increase in approval rate, rising from 71% to 90%. The second treatment had a

5% increase in approval. The third treatment had a 10% increase in approval, rising from 76% to 86%.

INTERPRETATION AND CONCLUSION

The original research question asked was: How does the implementation of simple math instruction tools help students in the science classroom to understand higher level science concepts? To answer this question, three sub questions and three treatments were used. The first treatment was a review of basic math skills that were needed to solve the problems presented in the new content for the day. The inspiration for this treatment was based on the case study published by Schell and Wicklein (1995). When the students were enrolled in a math/science/technology, cross curricular course, they found meaning in the math they were using in their class (Schell & Wicklein, 1995). Although, there was no math instructor consulted in the design or implementation of the review of math skills, it seemed like a logical warm-up to engage students' brains and grasp the connection and application of what was to be seen in the physical science class, and what was learned in the previous math class. This treatment seemed effective, because at some point, all students that participated in the study had a question about solving the problems that was presented to them. From a teaching standpoint, spending the first five minutes of class working on math skills saved time in the long run. At the end of the study, 90% of students responded favorably to the math warm-up and I felt that it was greatly beneficial to progress their learning. Using math warm-ups at the start of class, before the introduction of new science material, seemed to help students build a bridge between the two subjects by showing them the application of mathematics in science. It was observed that students who were enrolled in an AP Calculus course, even benefitted from the quick

reviews, because they were asking questions about math that they had not seen in a while. Students with less developed math skills had an opportunity to practice those skills and see applications to them that they may not have been exposed to in their current math classes.

The second treatment focused on scaffolding of problems. After students received direct instruction on the topic, they were given some guided practice problems that progressed in difficulty. Although 86% of students responded yes, the students who reported no had a good point about their experience. One student's response echoed the observation from this treatment that they, "became more lost because they didn't understand the original problem". This sentiment became obvious on days where the concepts were particularly challenging. A 2018 study by Zapalska, McCarty, Young-McLean, & White claimed that the most effective way critical thinking can be taught is through carefully constructed scaffolding, where one slowly and progressively makes their way through higher levels of understanding (Zapalska, McCarty, Young-McLean, & White, 2018). The concept of scaffolding is taught to teachers during their pedagogical training in their post-secondary education. To a certain extent, this strategy was executed, but seemed hindered by the rigorous pacing of the AP curriculum. The rate of student understanding varied from learner to learner, and from concept to concept, so the effectiveness of this tool may not have been used to the best of its advantages.

The third treatment implemented a mathematical graphic organizer. This tool was given to given to students during lectures and was implemented using direct instruction. When responding to the exit survey, only 86% found the tool useful, but the ones that

answered that they did not find it useful did not give any indication why. All the students participated in this treatment, but it was noticed that students who had a strong mathematics background did not use it much when working through guided practice problems or when doing lab work. It would be interesting to compare a control group of high math performers without the treatment versus a group of high math performers without the treatment. Mid to low math performers also did not seem to use the graphic organizers as a guide to help them with their guided practice or any lab work. This raises the question of why, if they were struggling with the material in the first place, did they not use those specific resources available to them? Was it because of their learning style, or was it some other reason? Professional research conducted with students who have slight to moderate learning disabilities recommended the use of a graphic organizer for understanding and making connections of background knowledge to new knowledge (Zollman, 2009). It is hard to determine if using this tool for students who do not necessarily have a slight or moderate learning disability was extremely beneficial. The effectiveness of this tool was inconclusive and requires more research.

Looking at assessment scores alone, it can be concluded that students did improve their scores from pre to post assessment. There was a mean five-point gain for the AP Chemistry course, and a mean three-point gain for AP Physics. The sample of students studied, did have a decrease in their overall science grades. It should be noted, that the grades recorded pre-study were pulled from the end of first semester of instruction. The study began at the beginning of second semester, as there were no grades at the time to report out. This study did conclude, prior to the student's spring break and right before

third quarter, that due to illness and school related activities, quite a few students were missing several assignments. The missing data in the gradebook could be a reason that the scores did not improve. The data collected, included labs and other activities that required proof of understanding of the content. The assessments mostly looked at foundational knowledge, with a small portion of the assessment evaluating higher order thinking and problem solving.

Lastly, when students were asked about their attitudes about both subjects, not surprisingly, most of the students who said they did not care for either math or science did have lower grades in both subjects. Throughout the entire study there was minimal changes in the student's attitudes. If this were conducted again, it would be interesting to evaluate if there was any change in attitudes from pre and post assessment from the individual trials.

VALUE

The purpose of this study was to find effective strategies to help students who struggle with the application of math in the science classroom. It was apparent, even before this study, students struggle to connect their math skills and apply them to their science learning. Teaching any advanced physical science classes require students to have strong basic algebra skills, and if their math skills are beyond the basics, it is extremely helpful in their understanding. Using these tools seemed to help to a certain extent, but it is felt that the tools used are not a substitute for solid math skills.

It seems that the most valuable tool used in the treatment was the simple warm-ups given at the start of class. The students with the higher math skills appreciated the

review of material that they may not have had to use in a long time; and the students with the lower math skills had a chance to practice applying their new math skills, and see an application beyond the realm of their math class.

The scaffolding of the problems was the biggest challenge with this study. Depending on the topic, some students were ready to move on to the harder work only after working through one to two simple problems. While, others seemed to need a lot more practice before moving onto the higher-level problems. If this treatment were to be given again, either some additional foundational problems need to be used for students that are struggling, or students need to be put into flexible groupings, according to their current needs. The problem sets were not differentiated in the treatment. So, it would be interesting to see if there would be any changes to the data.

The graphic organizers seemed to be most helpful to students who have a strong work ethic and behavior that indicated they genuinely wanted to understand the material. The students with that mindset were the ones who typically had their notes out and were asking clarifying questions when they were stuck on their work. When the information in the graphic organizer was given, all of the students participated in writing down the information, but when it came time to actually work through the problems, quite a few students just put the graphic organizers away, and attempted the problems without assistance. After reviewing student work, some found lots of success without the tool. Most of these students had extremely high-level math skills, while their peers made costly mistakes, such as not converting data into appropriate units. These mistakes could have been prevented, if the graphic organizer had been used as a guide.

Although, most students claimed that the prescribed treatments were helpful, it is hard to say if those treatments alone helped increase assessment scores. When the study was conducted, both courses were well underway. It is safe to say, that the students had little to no background on the topics studied. Had this been implemented during the beginning of the course, and multiple trials had been completed, it would have provided more conclusive data about the effectiveness of the treatments. It would have also been beneficial if there were multiple sections of the same courses to compare the scores of treatment vs. non treatment groups. If this study were to be conducted again, each treatment should be given separately to see if there is one that is more beneficial than the others. The examination of multiple different types of assessments would have provided an additional indicator of increase in critical thinking skills. This could be in the form of lab reports and design/build challenges. It would also be interesting to see if this study would have had different results if a certified math instructor or math coach put their input into the design of the tools used for treatment.

The idea for this study originated out of the frustration that students were unable or unwilling to apply their math skills in science class. When conducting the research for the conceptual framework of this study, it was very eye opening to see that there really is a cognitive disconnection between content subjects taught in a traditional public school system, and that it really isn't the fault of the students. This realization resulted in researching best practices for teaching beyond what is taught in a foundational pedagogy course. In a traditional K-12 public school, the content areas are chopped up throughout the day. As students enter the final years of their secondary education, this division

becomes more and more segregated as the content becomes more and more in-depth. This situation raises the question as to why the division? Critical thinking and problem-solving skills are needed to find success in any career and post-secondary training. This study is a reminder as to the importance of cross curricular collaboration, and that although teacher autonomy in the classroom is important, it is also important for teachers to collaborate with other educators outside their content area of expertise.

Personally, I found the math warm-ups incredibly helpful for all students to take 5 to 10 minutes at the start of class and access their background knowledge of their math skills. Short term, it did seem like it took up quite a bit of class time. But, in the long term, we were able to focus more on the new science content rather than the math skills needed to find success with the new material. Of all the treatments used, I felt that it was the simple math review at the start of class that was most effective, and I would encourage anyone, regardless of what level of physical science they are teaching, to utilize this method. When designing this study, it was helpful to look at the research centering around best practices and issues in the science classroom. During the implementation of the treatments, it had me reflect on what my practices were before implementing the treatments. As I prepare for the next school year, I plan on using the treatments in my practice and utilize them in all my classes.

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APPENDICES

APPENDIX A

IRB APPROVAL



MONTANA
STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

c/o Microbiology & Immunology	406-994-4707
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Bozeman, MT 59718	Administrator:
Telephone: 406-9944706	Cheryl Johnson
FAX: 406-9944303	406-994-4706
E-mail: cherylj@montana.edu	cherylj@montana.edu
2155 Analysis Drive	Chair: Mark Quinn

MEMORANDUM

TO: Irene Doyle and Marcie Reuer

FROM: Mark *Mark Quinn CH* Quinn
Chair, tional Review Board for the F Institutional Review Protection of
Human Subjects

DATE: November 14 2019

RE: "Bridging the Gap between Math and Science: Does the Review of Math Skills
Produce Student Growth in a Physical Science Class?" [KP111419-EX]

The above research, described in your submission of November 13, 2019, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

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 Research involving the use of educational tests (cognitive, diagnostic, aptitude,
achievement), survey procedures, interview procedures or observation of

public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation; and (iii) the information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by section 16.1 1 1a)(7).

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

b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded

by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.

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

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

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

APPENDIX B

CITI TRAINING CERTIFICATE



Completion Date 18-Feb-2019
 Expiration Date 17-Feb-2022
 Record ID 30636413



This is to certify that:

Irene Doyle

Has completed the following CITI Program course:

Social and Behavioral Research Investigators/ Faculty
Social & Behavioral Research - Basic/Refresher
1 - Basic Course

(Curriculum Group)
 (Course Learner Group)
 (Stage)



Under requirements set by:

Montana State University

Verify at www.citiprogram.org/verify/?w77101c41-4d6e-4942-a36c-10e90da93ee9-30636413

APPENDIX C
ENTRY AND EXIT SURVEYS

Hello!

I am currently in the process of completing my master's degree in science education and the university I am attending has tasked me with conducting an active research project to complete my degree. I am looking to you for help with this. If you could take 5 mins and answer this honestly, I would really appreciate it. The data I am collecting will be used for my project that will be presented in July to fellow educators and professors. Your personal information, including name, and grades will not be used; and if you choose not to participate, will not affect your grades. If you have questions, I would love to answer them.

-Ms. Doyle

What grade are you currently in?

Circle one: 9th 10th 11th 12th

What math class are you currently enrolled in?

Circle one:

Math 1 Math 2 Math 3 Math 4 Pre-calculus AP Calculus

AB

AP Calculus BC AP Statistics Other (CMC math, real world math, etc.)

What is your current grade in math class?

Circle one:

3.5 or higher 3.0-3.4 2.5-2.9 2.0-2.4 1.9 or lower

How well do you like science class?

Hate it!	1	2	3	4	5
Love it!					

If you answered 3 or less, please explain why?

How well do you like math class?

Hate it!	1	2	3	4	5
Love it!					

If you answered 3 or less, please explain why?

If you were given a very short math warm-up at the start of class that pertained to the physics/chemistry concept you are going to learn about today, do you think it would help you understand the material better?

Yes

No

If I were to slowly introduce a new chemistry/physics formula to you, do you think it would help you learn the material better?

Yes

No

If you were given a handout to help you organize the solving and analyzing physics/chemistry problems, do you think it would help you learn the material better?

Yes

No

Math and Science Attitudes Exit Survey

Hello!

I am currently in the process of completing my master's degree in science education and the university I am attending has tasked me with conducting an active research project to complete my degree. I am looking to you for help with this. My research has concluded for this project and if you could take 5 mins and answer this honestly, I would really appreciate it. The data that was collected will be used for my project that will be presented in July to fellow educators and professors. Your personal information, including name, and grades will not be used; and if you choose not to participate, will not affect your grades. If you have questions, I would love to answer them.

-Ms. Doyle

What is your current grade in math class?

Circle one:

3.5 or higher 3.0-3.4 2.5-2.9 2.0-2.4 1.9 or lower

How well do you like science class?

Hate it! 1 2 3 4 5

Love it!

If you answered 3 or less, please explain why?

How well do you like math class?

Hate it! 1 2 3 4 5

Love it!

If you answered 3 or less, please explain why?

After working on math warm-ups in class, do you think this helped you understand the material better? Yes No

Could you please tell me how this helped or did not help? (optional)

After working on problems that built on one another, do you think this helped you understand the material better? Yes No

Could you please tell me how this helped or did not help? (optional)

You were given a handout to help you organize the solving and analyzing physics/chemistry problems, do you think this helped you learn the material better?

Yes No

Could you please tell me how this helped or did not help? (optional)

APPENDIX D
MATH WARM-UPS

Newton's Universal Law of Gravitation Math Warm-Up

Please solve:

$$10.3^2 \quad \sqrt{9} \quad 1/3^2 \quad 6-2/7 \quad 9-3/6^2$$

Please write the following numbers in scientific notation:

$$.000349 \quad 12000000000 \quad .0000000000987 \quad 1987000000000000$$

Please solve:

$$3.4 \times 10^6 \times 36 \quad 8.9 \times 10^{-4} \times 21 \quad 3.4 \times 10^5 \times (1.2-.6)/5^2 \quad 4.7 \times 10^{-7} \times (14-9)/7^2$$

Circular Motion Math Warm-Up 1

Please solve:

What is the radius of a circle with a 6 m diameter?

What is the area of a circle with a radius of 2 m?

What is the circumference of a circle with a diameter of 4 m?

Circular Motion Math Warm-Up 2

Consider the following:

$$x = (2+3)/6$$

$$y = (4-2)/1$$

Please solve:

$$x+7$$

$$y-6$$

$$x+y$$

Torque Math Warm-Up**Please solve the following:**

$$23+x=90 \quad 45+x=90 \quad 77+x=90 \quad \sin(30) \quad \sin(63)$$

$$500+3 \sin(35) \quad 250(3) [\sin(24)] \quad 159(20)[\sin(29)]$$

Rotational Motion Math Warm-Up**Please convert the following from degrees to radians:**

$$180^\circ \quad 360^\circ \quad 210^\circ \quad 120^\circ$$

Please solve:

$$(2-7)/(6-2) \quad (x-2)/(10-4)=12 \quad (4-x)/6=20$$

Thermodynamics Math Warm-Up 1**Please solve the following:**

$$\begin{array}{l} -3+2 \\ 12=3.48(2x) \end{array}$$

$$-3.87+1.90$$

$$3x+6=2x+4$$

$$5x(3-6)=2x(4+7)$$

$$5.6=2.94(4.71)(x+6)$$

Thermodynamics Math Warm-Up 2**Please solve the following:**

$$24+456+(-234)+1239$$

$$345+(-987)+267+1298$$

$$(-236)+23+222+(-345)$$

Kinetics Math Warm-Up 1**Please complete the following calculations:**

$$2^3 \underline{\hspace{2cm}}$$

$$2.34(1.47) \underline{\hspace{2cm}}$$

$$3.78(1.26)^2 \underline{\hspace{2cm}}$$

If $x=6$, $y=4$, and $n=2$ please complete the following equation: $x(y)^n$ **Kinetics Math Warm-Up 2****Please solve:**

$$-6(4)+12$$

$$-4(5)+21$$

$$\ln(4)$$

$$\ln(9)$$

$$-6(2)+\ln(5)$$

Solve for x:

$$\ln(4)=-4x+6 \quad \ln(3)=-7(6)+\ln(x) \quad \ln(x)=-4(8)=5$$

APPENDIX E
GUIDED PRACTICE PROBLEMS

Newton's Universal Law of Gravitation
Guided Practice Problems*
AP Physics 1

Name: _____

1. What is a fundamental force?
2. The moon has an acceleration of 6.78 m/s^2 , how much would you weigh on the moon?
3. Draw and label a free body diagram from the situation described in question 2.
4. What is Newton's Universal Law of Gravitation? Please list out each variable.
5. A certain asteroid in our galaxy has a mass of $2.7 \times 10^{11} \text{ kg}$ and has a distance of $8.91 \times 10^5 \text{ km}$ from Jupiter. What is the gravitational force exerted on the asteroid by Jupiter? (Hint: Jupiter has a mass of $1.89 \times 10^{27} \text{ kg}$.)
6. What is the gravitation force of you on your classmate?

*Problems modified from College Physics AP Edition.

Circular Motion

Guided Practice Problems*

AP Physics 1

Name: _____

What is it?

Key Formulas:

Velocity:	Radial Acceleration:	Centripetal Force:	Circumference:	Period:

An object traveling in a circle has a period of .75 s, and a radius of 1.7 m from its origin. What is its velocity?

Using the information from the above question, what is its radial acceleration?

Your classmate is swinging a set of keys attached to a lanyard over their head in a horizontal, circular path. The piece of string is 2 m long and the ball makes 20 complete turns each minute.

- What is the average velocity of the ball?
- What is the ball's centripetal acceleration?

*Problems modified from College Physics AP Edition.

Torque
Guided Practice Problems*
AP Physics 1

Name: _____

What is torque?

What is the formula for torque?

If you were given a wrench that is .125m long how much torque would be required to turn the bolt 30°?

You need 9 Nm of torque to safely tighten a bolt for a steel chainring on a bicycle. If you are using a wrench that is .125 m long how far would you have to turn it?

*Problems modified from College Physics AP Edition.

Rotational Motion
Guided Practice Problems*
AP Physics 1

Name: _____

1. What do the following variables designate:

ω :	α :
θ :	r :

2. If an object rotated 50° , how far did its position change in radians?
3. A matchbox car is traveling around a perfectly circular track and has moved 274° .
Derive a formula to find the displacement of the truck.
4. A record is turning at 45 rad/sec. If it plays an intro track that is 90 seconds long, what was the displacement of the needle while it was playing?

*Problems modified from College Physics AP Edition.

Thermodynamics
Guided Practice 1*
AP Chemistry

Name: _____

1. Identify the following as exothermic or endothermic. Please label each process with their appropriate sign:
 - Gasoline burning
 - Water freezing in a pond
 - Sweat evaporating from skin
 - A chemical ice pack

2. A cylinder in an engine is warmed by the chemical reaction of octane and oxygen. When the chemical reaction takes place, the piston in the cylinder moves away from the cylinder, doing work on the surroundings. If the system absorbed 700 J of heat, and does 372 J of work during this reaction, what is the value of ΔE ?

3. A 60g aluminum block initially at 27.5C absorbs 850 J of heat. What is the final temperature of the aluminum?

4. Suppose you are cold weather camping and have the option to bring a jug of water or a rock for added warmth. The jug of water and rock have equal mass, and initially the same temperature, both eventually warm to 38 C. Which item would be the better choice for a decent night's sleep? Explain your answer.

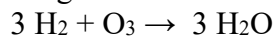
5. A block of copper of unknown mass has an initial temperature of 65.4 C. The copper is immersed in a beaker containing 95.7g of water at 22.7 C. When the two substances reach thermal equilibrium, the final temperature is 24.2 C. What is the mass of the copper block?

*Problems modified from Chemistry: A Molecular Approach AP Edition

Thermodynamics
 Guided Practice 2*
 AP Chemistry

Name: _____

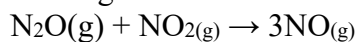
1. Find the ΔH_{rxn} for the following reaction:



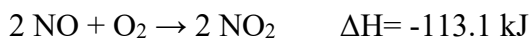
Use these reactions with known ΔH :



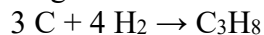
2. Find the ΔH_{rxn} for the following reaction:



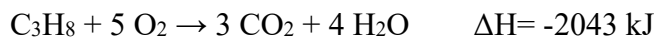
Use these reactions with known ΔH :



3. Find the ΔH_{rxn} for the following reaction:



Use these reactions with known ΔH :



Kinetics

Guided Practice 1*

AP Chemistry

Name: _____

1. Why is the reaction rate for reactants defined as negative or the change in reactant concentration with respect to time and whereas for products it is defined as the change in reactant concentration with respect to time (with a positive sign)?

2. Consider the following reaction:



What is the rate change in the concentration of hydrogen peroxide ($\Delta[\text{H}_2\text{O}_2]/\Delta t$) and ionic iodine [$\Delta \text{I}_3^-/\Delta t$] during a 10 s period of time?

3. Consider the following reaction:



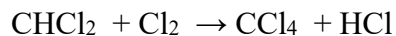
Under a set of given conditions, the initial rate is .100 M/s. What is the $\Delta [\text{B}] / \Delta t$ under the same conditions?

- a. -.0500 M/s b. -.100 M/s c. -.200 M/s

4. The reaction $\text{A} \rightarrow \text{B}$ has been experimentally determined to be second order. The initial rate is .0100 M/s at an initial concentration of A of .100 M. What is the initial rate at $[\text{A}] = .500 \text{ M}$?

- a. .00200 M/s b. .0100 M/s c. .0500 M/s d. .250 M/s

5. Consider the following reaction:



The initial rate of the reaction is measured experimentally at several different concentrations of the reactants with the following results:

[CHCl ₂] (M)	[Cl ₂] (M)	Initial rate (M/s)
.010	.010	.0035
.020	.010	.0069
.020	.020	.0098
.040	.040	.027

From the data above determine:

- the rate law for the reaction
- the rate constant (k) for the reaction

APPENDIX F
GRAPHIC ORGANIZER

What do we know?	List all the variables we know below:
What do we want to know?	List what we want to know, including what we need to find the correct solution:
Housekeeping?	What do we need to do to be able to set this problem up?
Formula(s):	Write the correct formula(s) below:

Solve:	
---------------	--

APPENDIX G

PRE AND POST ASSESSMENTS FOR AP PHYSICS 1 AND AP CHEMISTRY

Circular Motion and Gravitation

Pre-assessment *

AP Physics 1

Name: _____

1. Gravity is considered:
 - a. A fundamental force
 - b. A physical force
 - c. A natural force
 - d. A kinematic force
2. Three fundamental forces are:
 - a. Gravitational, electronegative, weak
 - b. Gravitational, electroweak, and strong
 - c. Gravitational, restoring, and normal
 - d. Gravitational, weight, and tension
3. Which statement is **TRUE** about Newton's Universal Law of Gravitation?
 - a. The smaller the mass the greater the gravitational pull
 - b. The larger the mass the smaller the gravitational pull
 - c. The bigger the distance between the two objects the greater the pull
 - d. The smaller the distance between the two objects the greater the pull
4. On the moon, which scenario would most likely happen with your weight?
 - a. Your weight would increase
 - b. Your weight would not change
 - c. Your weight would decrease
 - d. Your weight would exponentially increase
5. Which variable represents the gravitational force?
 - a. G
 - b. g
 - c. F_g
 - d. G_f

Please solve the following problems:

You must show all work and units to receive full credit.

6. The centripetal acceleration of a ball on a string is 5m/s^2 , and is traveling at a velocity of 2m/s . How long is the string attached to the ball?

7. You are sent to Mars on an expedition, once entering the atmosphere please estimate the gravitational pull of the planet on your 4500 kg spaceship. The mass of Mars is 6.39×10^{23} kg.

Circular Motion and Gravitation

Name: _____

Post Assessment*

AP Physics 1

1. Gravity is considered:
 - a. A fundamental force
 - b. A physical force
 - c. A natural force
 - d. A kinematic force
2. Three fundamental forces are:
 - a. Gravitational, electronegative, weak
 - b. Gravitational, electroweak, and strong
 - c. Gravitational, restoring, and normal
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 - d. Your weight would exponentially increase
5. Which variable represents the gravitational force?
 - a. G
 - b. g
 - c. F_g
 - d. G_f

Please solve:

You must show all work and units to receive full credit.

6. The centripetal acceleration of a ball on a string is 5m/s^2 , and is traveling at a velocity of 2m/s . How long is the string attached to the ball?

7. You are sent to Mars on an expedition, once entering the atmosphere please estimate the gravitational force of the planet on your 5000 kg spaceship. The mass of Mars is 6.39×10^{23} kg.

Short answer:

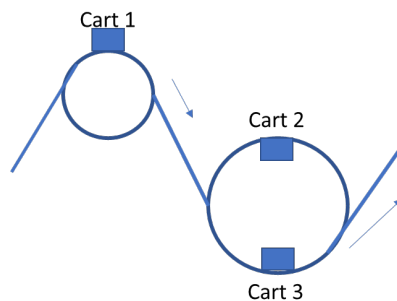
8. Consider the situations below, which **best** describes a situation where the gravitational force the dominant force? Explain why you chose this response.

- The Earth is orbiting the sun.
- A water balloon is launched from a sling.
- Two atoms are bonded together.
- A boulder is resting on the side of a mountain.

9. Talking to any scientist at NASA, they will tell you that the Earth's orbit is not perfectly circular, but elliptical. If you were to look at the path that the Earth takes around the sun you would notice that the sun is at the far end of the ellipse, and the speed of the elliptical orbit varies in comparison to the position of the Earth and Sun. What is a reasonable explanation of this phenomenon?

Free Response Question:

Consider the following diagram:



Circle one of the three carts and draw and label a free body diagram.

Draw a box around the situation that has the greatest angular velocity. Why did you choose this position?

Draw a triangle around the situation that has the greatest centripetal force. Why did you choose this position?

Derive an equation that would help find the radial acceleration of the situation that has the greatest angular velocity.

If the mass of the cart were to increase, predict what would happen to the force.

*Problems modified from College Physics AP Edition.

Rotational Motion and Rigid Bodies

Name: _____

Pre-assessment *

AP Physics 1

1. Angular momentum is:
 - a. The sum of moment of inertia and angular velocity
 - b. The square root of angular velocity
 - c. The difference of angular velocity and momentum
 - d. The product of moment of inertia and angular velocity
2. The units for moment of inertia are:
 - a. N
 - b. $\text{Kg} \cdot \text{m}^2$
 - c. $\text{Kg}^2 \cdot \text{m}$
 - d. Kg/m
3. What is the symbol for angular momentum?
 - a. N
 - b. A
 - c. L
 - d. F
4. Which equation should be used for the moment of inertia of a ring about an axis?
 - a. $\frac{1}{2} M \cdot R^2$
 - b. $M \cdot R$
 - c. $\frac{1}{2} M \cdot R$
 - d. $M \cdot R^2$
5. An ice skater is spinning fast with her arms tight against her body. When she extends her arms, which of the following statements is not true?
 - a. She increases her moment of inertia.
 - b. She decreases her angular velocity.
 - c. Her moment of inertia remains constant.
 - d. Her total angular momentum will remain constant.
6. What does the moment of inertia describe?
 - a. The average position of mass in an extended object.
 - b. How the mass of an object is distributed about a rotational axis.
 - c. An objects resistance to angular acceleration
 - d. The tendency of an object to move in a straight line.

7. Which is the best description of torque?
- a. The force required to push an object a specific distance
 - b. The force required to pull an object
 - c. The force required to rotate an object to a specific angle
 - d. The force required to swing an object a specific distance
8. Where would you find the center of mass in an object that is symmetrical and has an evenly distributed density?
- a. The most outward area of the object
 - b. In its exact center
 - c. To the left of its exact center
 - d. It is completely dependent on the object.

Please solve.

You MUST show all work and units to receive full credit.

A disc rotates through 6 radians in 9 seconds. The disc experienced uniform acceleration. If the disc starts from rest, what is the angular velocity after four seconds?

Rotational Motion and Rigid Bodies

Name: _____

Post Assessment*

AP Physics 1

1. Angular momentum is:
 - a. The sum of moment of inertia and angular velocity
 - b. The square root of angular velocity
 - c. The difference of angular velocity and momentum
 - d. The product of moment of inertia and angular velocity
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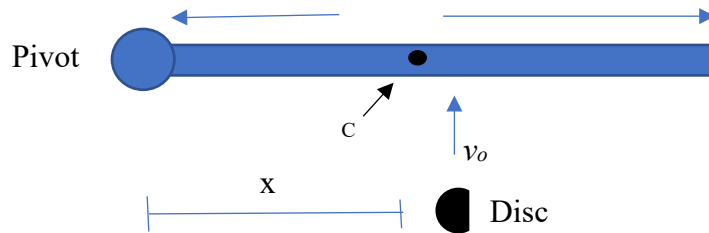
Please solve. You MUST show all work and units to receive full credit.

A disc rotates through 6 radians in 9 seconds. The disc experienced uniform acceleration. If the disc starts from rest, what is the angular velocity after four seconds?

You just scored a free wheelbarrow and want to fix it up for a physics contest. The problem is that you have no idea how long the original handles were. Its original owner said the wheelbarrow used to be able to pick up a 500 N load and due to its size cannot exceed an angle of 50° . At the lumber store you have a choice between a .25 m and a .5m handles. Which one would be the better choice? Justify your answer. To receive full credit, you must include a F.B.D that is labeled, and your calculations must have work and correct units. You must also declare which choice is most appropriate.

Free Response Question**

Consider the diagram below:



A rod attached to a frictionless pivot has a length of d and the rotational inertia I . Point C marks the center of the rod, and it is resting on a frictionless surface. Initially the rod is motionless but is free to rotate around the pivot. A student slides a disc toward the rod with velocity v_o , perpendicular to the rod and the disc will stick to the rod at distance x from the pivot. The student wants the rod-disc system to end up with as much angular speed as possible.

- Suppose the rod is much more massive than the disc. To give the rod as much angular speed as possible should the student make the disc hit the rod to the left, right or center of point C ? Explain your reasoning.

*Problems modified from College Physics AP Edition.

**Free response question modified from released College Board 2017 AP Physics 1 Free-response Question

Thermodynamics

Pre-assessment *

AP Chemistry

Name: _____

1. The first law of thermodynamics is:
 - a. Matter is neither created or destroyed
 - b. Energy is neither created or destroyed, but conserved
 - c. Momentum is always conserved
 - d. None of these

2. Energy associated with the temperature of an object is called
 - a. Thermal Energy
 - b. Potential Energy
 - c. Kinetic Energy
 - d. All of these

3. What is true about all matter in the universe:
 - a. It has energy associated with it
 - b. It has mass and takes up space
 - c. a and b
 - d. None of these

4. A chemical ice pack is an example of a:
 - a. Endothermic reaction with a $-\Delta H$
 - b. Exothermic reaction with a $-\Delta H$
 - c. Endothermic reaction with a ΔH
 - d. Exothermic reaction with a ΔH

5. Which of the following would have the **smallest** change in temperature if 250 J of thermal energy were to be applied to it?
 - a. 50 g of Al, $c_{sp} = .903 \text{ J/g } ^\circ\text{C}$
 - b. 50 g of Cu, $c_{sp} = .385 \text{ J/g } ^\circ\text{C}$
 - c. 50 g of Au, $c_{sp} = .128 \text{ J/g } ^\circ\text{C}$
 - d. 50 g of granite, $c_{sp} = .79 \text{ J/g } ^\circ\text{C}$

6. Calorimetry is:
 - a. A way to measure work in a system
 - b. A way to measure the heat exchange of an object in a system
 - c. A way to measure energy in a system

- d. A way to measure temperature in a system
7. An example of a state function is:
- a. Enthalpy
 - b. Work
 - c. Hess's Law
 - d. A and B
8. An example of a system would be:
- a. Ice in a glass of water
 - b. Salt on a sidewalk
 - c. Water surrounding a beaker
 - d. A and B
9. In an exothermic reaction
- a. Heat is released
 - b. Heat is absorbed
 - c. Heat is destroyed
 - d. Heat is transformed into another form of energy
10. If 497 J/mol of energy is required to break a bond of a specific molecule, how much energy would be needed to form it?
- a. 497
 - b. -497
 - c. 248.5
 - d. Not enough information is given

Short Answer:

11. If 345 J of heat is put into a system producing 45 J of work, what is the change of internal energy?
13. If 400 kJ of energy is released into the surroundings, how much energy was lost in the system? Explain your answer.

*Problems modified from Chemistry: A Molecular Approach AP Edition

Thermodynamics

Post Assessment*

AP Chemistry

Name: _____

1. The first law of thermodynamics is:
 - a. Matter is neither created or destroyed
 - b. Energy is neither created or destroyed, but conserved
 - c. Momentum is always conserved
 - d. None of these

2. Energy associated with the temperature of an object is called
 - a. Thermal Energy
 - b. Potential Energy
 - c. Kinetic Energy
 - d. All of these

3. What is true about all matter in the universe:
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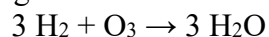
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- a. 497
 - b. -497
 - c. 248.5
 - d. Not enough information is given

Short Answer:

11. If 345 J of heat is put into a system producing 45 J of work, what is the change of internal energy?
13. If 400 kJ of energy is released into the surroundings, how much energy was lost in the system? Explain your answer.

14. A block of copper of unknown mass has an initial temperature of 54.2 C. The copper is immersed in a beaker containing 30g of water at 22.7 C. When the two substances reach thermal equilibrium, the final temperature is 29.5 C. What is the mass of the copper block?

15. Find the ΔH_{rxn} for the following reaction:



Use these reactions with known ΔH :



*Problems modified from Chemistry: A Molecular Approach AP Edition

Kinetics

Name: _____

Pre-assessment *

AP Chemistry

- Give the characteristic of a second order reaction having only one reactant.
 - The rate of the reaction is not proportional to the concentration of the reactant
 - The rate of the reaction is proportional to the square of the concentration of the reactant
 - The rate of the reaction is proportional to the square root of the concentration of the reactant.
 - The rate of the reaction is proportional to the natural logarithm of the concentration of the reactant
- What is the overall order of the following reaction, given the rate law?

$$\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2 \quad \text{Rate} = k[\text{NO}][\text{O}_3]$$
 - 1st order
 - 2nd order
 - 3rd order
 - 0th order
- When Carbon-14 decays it has a half life of 5720 years and is a first order reaction. If a piece of wood has converted 75% of the carbon-14 then how old is it?
 - 11440 years
 - 2375 years
 - 4750 years
 - 4290 years
- Which of the following represents the integrated rate law for a first order reaction?
 - $\ln[A]_t/[A]_0 = -kt$
 - $1/[A]_t - 1/[A]_0 = kt$
 - $[A]_t - [A]_0 = -kt$
 - $k = Ae^{(-E_a/RT)}$
- What should be plotted to show that experimental concentration data fits a first order reaction?
 - $1/[\text{reactant}]$ vs. time
 - $[\text{reactant}]$ vs. time
 - $\ln [\text{reactant}]$ vs. time
 - $\ln(k)$ vs. $1/T$

6. Which of the following statements is **false**?
- The average rate of reaction decreases during a reaction.
 - It is not possible to determine the rate of a reaction from its balanced equation
 - The rate of zero order reactions are not dependent on concentration.
 - The half-life of a first order reaction is dependent on the initial concentration of reactant
7. The rate determining step can generally be defined as:
- The slowest step
 - The fastest step
 - The middle step
 - The first step
8. For a reaction, what generally happens if the temperature is increased?
- A decrease in k occurs, which results in a faster rate.
 - A decrease in k occurs, which results in a slower rate
 - An increase in k occurs, which results in a faster rate
 - An increase in k occurs, which results in a slower rate.
9. For the reaction: $2 \text{NH}_2 \rightarrow \text{N}_2 + 2\text{H}_2$ the rate expression for the appearance of NH_2 in the forward reaction rate is: $k[\text{NH}_2]^2$. If the volume of the container is halved, doubling the concentration for all the ingredients, at constant temperature, the reaction rate will increase by a factor of:
- 2
 - 4
 - 6
 - 8

Please match the following to the best answer:

- | | |
|--|----------------------|
| 10. k _____ | A. Frequency factor |
| 11. n , in $\text{Rate} = k[\text{A}]^n$ _____ | B. Half-life |
| 12. $t_{1/2}$ _____ | C. Reaction order |
| 13. E_a _____ | D. Activation Energy |
| 14. A _____ | E. Rate constant |

Kinetics

Post Assessment*

AP Chemistry

Name: _____

1. Give the characteristic of a second order reaction having only one reactant.
 - a. The rate of the reaction is not proportional to the concentration of the reactant
 - b. The rate of the reaction is proportional to the square of the concentration of the reactant
 - c. The rate of the reaction is proportional to the square root of the concentration of the reactant.
 - d. The rate of the reaction is proportional to the natural logarithm of the concentration of the reactant

2. What is the overall order of the following reaction, given the rate law?
$$\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2 \quad \text{Rate} = k[\text{NO}][\text{O}_3]$$
 - a. 1st order
 - b. 2nd order
 - c. 3rd order
 - d. 0th order

3. When Carbon-14 decays it has a half-life of 5720 years and is a first order reaction. If a piece of wood has converted 75% of the carbon-14 then how old is it?
 - a. 11440 years
 - b. 2375 years
 - c. 4750 years
 - d. 4290 years

4. Which of the following represents the integrated rate law for a first order reaction?
 - a. $\ln[A]_t/[A]_o = -kt$
 - b. $1/[A]_t - 1/[A]_o = kt$
 - c. $[A]_t - [A]_o = -kt$
 - d. $k = Ae^{(-E_a/RT)}$

5. What should be plotted to show that experimental concentration data fits a first order reaction?

- a. $1/[\text{reactant}]$ vs. time
- b. $[\text{reactant}]$ vs. time
- c. $\ln [\text{reactant}]$ vs. time
- d. $\ln(k)$ vs. $1/T$

6. Which of the following statements is **false**?

- a. The average rate of reaction decreases during a reaction.
- b. It is not possible to determine the rate of a reaction from its balanced equation
- c. The rate of zero order reactions are not dependent on concentration.
- d. The half-life of a first order reaction is dependent on the initial concentration of reactant

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- b. The fastest step
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- d. The first step

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- a. A decrease in k occurs, which results in a faster rate.
- b. A decrease in k occurs, which results in a slower rate
- c. An increase in k occurs, which results in a faster rate
- d. An increase in k occurs, which results in a slower rate.

9. For the reaction: $2 \text{NH}_2 \rightarrow \text{N}_2 + 2\text{H}_2$ the rate expression for the appearance of NH_2 in the forward reaction rate is: $k[\text{NH}_2]^2$. If the volume of the container is halved, doubling the concentration for all the ingredients, at constant temperature, the reaction rate will increase by a factor of:

- a. 2
- b. 4
- c. 6
- d. 8

Please match the following to the best answer:

- | | |
|--|----------------------|
| 10. k _____ | A. Frequency factor |
| 11. n, in Rate=k[A] ⁿ _____ | B. Half-life |
| 12. t _{1/2} _____ | C. Reaction order |
| 13. E _a _____ | D. Activation Energy |
| 14. A _____ | E. Rate constant |

Consider the reaction: $2\text{NO} + 2\text{H}_2 \rightarrow \text{N}_2 + 2\text{H}_2\text{O}$

An experiment was conducted to study the rate of the reaction above. In the table below, the following results were reported:

Trial	Initial concentration (mol/L) [NO]	Initial Concentration(mol/L) [H ₂]	Initial rate of formation N ₂ (mol/L min)
1	.0060	.0010	.0012
2	.0060	.0020	.0025
3	.0030	.0020	.0013.
4	.0060	.0060	.0072

- Determine the order for each of the reactants, NO and H₂, from the data given and show your reasoning.
- Write a rate law for this reaction.
- Calculate the value of the rate constant k, for the reaction. YOU MUST INCLUDE UNITS TO GET FULL CREDIT
- For trial 2, calculate the concentration of NO remaining when exactly one- half of the original amount of H₂ has been consumed.

*Problems modified from Chemistry: A Molecular Approach AP Edition

