# USING A BALANCE OF MATHEMATICAL AND CONCEPTUAL PRACTICE PROBLEMS TO INCREASE UNDERSTANDING IN HIGH SCHOOL PHYSICS

by

Scott Christopher Andrews

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

of

Master of Science

in

Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2022

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## ABSTRACT

This study investigated the impact of a balanced combination of conceptual and mathematical practice problems on students in $11^{th}$ grade physics class. For the first unit of study on describing motion, students in the treatment class answered many conceptual problems before working on mathematical practice problems. In the comparison class, students worked on nearly all mathematical practice problems with a few conceptual problems toward the end of the sessions. This problem solving occurred in the “Explain” phase of the 5E instructional model. After unit one, the treatment and comparison classes were switched for unit two on forces and acceleration to determine if there were any similar results. The students’ progress was analyzed by comparing a summative unit pre-test with a post-test in addition to formative assessment, student surveys and interviews. Initially, it appeared that female students improved their test scores to a higher degree than male students with the concepts first approach. However, the unit two results indicated that the average student made high gains with a concepts first approach in the treatment class or a nearly even balance of conceptual and mathematical problem solving in the comparison class.

# INTRODUCTION AND BACKGROUND

## Context of the Study

The Department of Defense Education Activity (DoDEA) school system was located in many areas around the world and served nearly 67,000 students this past school year. There were about 625 students in our school, and I determined from my work on the school's continuous-improvement learning-community that everyone was essentially an ethnic minority. The student body was composed of roughly 25% Asian students, 25% Black, 25% Caucasian and 25% mixed ethnicities which continuously fluctuated as students and their families rotate onto base and then transfer back to the states or to a different post. Approximately 30% of our students were new to our school or have left during any school year. My physics classes had 19 students, comprised of ten females and nine males that met during section A2, and 21 students, comprised of eleven females and ten males that met during section B4. I found the students were extremely respectful and kind to each other, probably due to being overseas and in a military connected environment.

The DoDEA school system has adopted Next Generation Science Standards (NGSS) for physics and added the graduation requirement that all students take physics their junior year. The adopted textbook and the standards themselves were quite concept oriented as opposed to the traditional mathematical problem-solving approach often seen in high school physics classes. Rather than weeding out students from a potential STEM (Science, Technology, Engineering, and Math) career due to a weakness in computational reasoning, it was thought that standards could remain high with an emphasis in qualitative reasoning supported by mathematical analysis.

During interviews that I conducted with three of my physics teaching colleagues, I determined that all of us found our newly adopted textbook (Houghton Mifflin Harcourt Science Dimensions Physics) to lean heavily on the conceptual ideas of physics, lacking mathematical explanation or practice problems. The need to strike a balance between the conceptual and mathematical approaches seemed to be a common issue.

## Focus Question

My action research project topic was the impact of a balanced combination of conceptual and mathematical practice problems on students in 11$^{th}$ grade physics class. I had a concern that I tended to work on guided practice problems too frequently at the expense of the physics concept in question. I didn't want my students to arrive at a mathematical answer but have no idea of what it indicated.

My sub-questions included the following:

1. How well did students improve in their comprehension of the information during the units of study?
2. What were the student attitudes during the units of study?
3. How did teaching these units impact me as an educator?

I taught unit one on describing motion, and unit two on forces and acceleration using a balance of conceptual and mathematical questions from "The Physics Classroom" (https://www.physicsclassroom.com/) with students in my treatment class. I did not utilize these specific questions in my comparison class but instead taught using a more mathematical problem-solving approach. This treatment occurred during the third “E” of the 5E instructional model (Engage, Explore, Explain, Elaborate, Evaluate). The rest of the lessons, to include modeling investigations, a student inquiry project, and guided inquiry laboratory investigations, remained the same for both classes.

I looked at differences between pre-tests and post-tests in each group. These tests were developed collaboratively with my team of regional physics educators. The questions on the test were selected to represent what we collectively felt was important to assess from our common scope and sequence. The tests included a balance of conceptual, combination of conceptual and mathematical, and calculation-based questions.

In this mixed-methods research design, I utilized formative assessments, surveys, and student interviews to gauge their understanding and attitudes. During the school year I kept a reflective journal of my thoughts and observations as to the impact of this curriculum change on myself as an educator.

My group of collaborative physics teaching peers met each Tuesday for 90 minutes and discussed best practices, shared lab ideas, developed common assessments, and analyzed results. These five individuals have heard from me on a weekly basis, and I have shared my results with them.

# CONCEPTUAL FRAMEWORK

My action research project helped me to focus on the challenge of providing my physics students with a rigorous course designed to meet the NGSS standards. To that end, I read articles that would help in the direction of my work. In general, these papers indicated that mathematical problem solving alone did not provide students with mastery of physics content and skills. They suggested that students needed a conceptual method to understand the problem first, before trying to work out a solution, and determine if it was appropriate.

## Topic Research

A version of a problem-solving method where students do not just jump to known, unknown and manipulate an equation to solve was described in one. There are four steps which begin with qualitative visualization and description of the problem before solving for an unknown and a continuous explanation of the process and results. The authors demonstrated that in their control group students who routinely headed straight for a mathematical solution to a problem, were much less likely to solve the problem correctly compared to their experimental group who first explained the problem and how the laws of physics applied. This ability was tracked in two subsequent semesters and held true for up to 12 months that were examined. However, neither group successfully solved the problems a majority of the time, indicating the need for improved instruction and student perseverance (Becerra et at., 2012).

A second article (Oliveira, 2013) provided some background for my question on student attitudes and motivation. Discourse was a major element of the conceptual problem solving where students had to come to an understanding of physics concepts through argumentation and explaining ideas in their own words. These student-led discussions were enjoyable and motivating as ascertained by student surveys. In addition, students were able to make more connections to situations in the real world.

## Theoretical Research

The theoretical underpinnings of my action research project reach forty or more years back when Paul Hewitt started providing college students with a conceptual physics course. He recommended that students start with conceptual reasoning as a significant part of problem solving before introducing the mathematical relationships (Hewitt, 1983). In his high school textbook, he claimed that teaching the algebraic solution first, obscures the physics concept and recommended the concept first approach (Hewitt, 1992). In a personal e-mail message, he added that “in my courses, I feature NO problem solving, as I have only 16 weeks to build a love of physics in my students. If a learner’s first physics course is delightful, they’ll welcome the rigor of a second course.”

This assertion was supported by research completed using a problem-solving protocol called ACCESS. Over a three-year period of study, a team of researchers found an equitable balance between conceptual understanding and problem-solving practice. Previous years demonstrated that problem-solving skills were acceptable, but scores on the force concept inventory were quite low (Ridenour et al., 2013).

## Methodology Research

Data collection and analysis methodology were well designed in a study comparing a textbook problem-solving approach to a treatment called the explicit problem-solving strategy (Huffman, 1997). The author discovers that there was not much difference between the two methods except that for male students the textbook problem-solving approach seemed to result in a larger gain of understanding, but for the explicit problem-solving strategy, females had improved more. Selecting specific sub-groups, such as gender, or incoming GPA, to study the effect of the treatment was part of my proposal. Monitoring student buy-in was accomplished using student survey data which I also utilized to gain an understanding of student attitudes.

In a second methodology article there was a description of a similar situation. To tackle the gap between conceptual knowledge and mathematical problem solving, the authors required students to write about the physics principles that were involved in the problem and how they applied. The study involved three instructors and approximately 150 college students enrolled in introductory physics for scientists and engineers. They found that 48% of the students in the traditional group could identify the concepts correctly compared to 70% of the students in the strategies group (the treatment group). They did a follow-up phone survey with select members of each group and found that the strategies group had a lasting comprehension as to what physics concepts applied to specific problems even months later (Leonard et al., 1996).

## Related Research

Other related articles compared “active learning plus concepts first” with “active learning only” and determined that the concepts first class was strikingly positive for underrepresented minority groups in physics (Webb, 2017). A study of Japanese students that had already taken an introductory physics course, uncovered in a subsequent class that they preferred having a physical understanding of the problem rather than just a “plug and chug” type solution. This study was conducted through student interviews. (Hull et at., 2013).

Two college professors designed a study of two high school classes which were taught mathematical problem-solving first and then a conceptual discussion and the treatment group the reverse. They found a slightly higher normalized gain for the treatment group on an eight-question post-test and added some insight on preconceived notions about two-dimensional motion that high school students carry with them to college (Sadaghiani & Aguilera, 2013).

Finally, in a summary of research findings (McDermott, 2001) there were six generalizations about students learning physics and six generalizations about teaching physics. These pointed toward a conceptual first instructional framework as being more effective for students and how testing on mathematical problem-solving ability was not adequate for gauging student ability.

Overall, the need for a conceptual understanding of physics problems before jumping into mathematical problem solving seemed overwhelmingly apparent in these papers. Where the research seemed to be lacking, was in the quantity of conceptual problems compared to mathematical problems that students attempted. The focus of my project was to determine the necessary balance between the two that increased student understanding in high school physics.

# METHODOLOGY

The research methodology of this study was designed as a combination of quantitative, qualitative, and interpretation of the data and results, known as a triangulation mixed-methods design. An exemption by Montana State University's Institutional Review Board was not obtained, (see Appendix A).

## Treatment

The Physics Classroom was a huge website that offered many practice problems in conjunction with concept building explanations. It was often highly recommended for teachers new to physics to utilize this site to brush up on their skills and to assign work for their students. I used questions from the "Minds On Physics Version 5" portion of this website as my treatment. These questions provided a balance of conceptual and mathematical practice problems which I hoped would result in a significant gain in comprehension for my students.

Students in the treatment class were asked about 20 conceptual questions first, such as "What does the slope on a position-time graph represent?" or "When the position-time graph line is drawn upward with a constant slope, what is the object doing?" Students subsequently looked at the magnitude of the slope to determine quantitative answers. Additionally, these students were given a second part to the question which was to change a value, such as the slope, and determine the new answer. Finally, students were asked to write a sentence or two on how the change affected the answer. This class was the treatment group for eight weeks and then they were switched to become the comparison group for another four weeks.

Students in the comparison class looked at the slope from a mathematical perspective and derived meaning from practice problems with discrete answers. This approach followed my current teaching methods for my physics classes which have been utilized for many years. Students often stated that they enjoyed arriving at "an answer" and demonstrating the use of their mathematical skills. However, my concern was that the approach does not work equally well for all my students, and that everyone may benefit from a concepts first method. This class was the comparison group for eight weeks and then they became the treatment group for another four weeks. Both groups of students monitored and reported how many questions were conceptual, mathematical, or a combination of both during each class.

## Data Collection and Analysis Strategies

Using a pre- and post-test for the first two units of study in my physics classes, I intended to track the improvement in student's scores as a whole class and conduct an item analysis of the questions. I also looked at sub-groups of students such as by gender, incoming GPA, and PARCC (Partnership for Assessment of Readiness for College and Careers) math test score, to determine if there was an outlying impact on any of these populations. Any additional gains in the treatment group could be attributable to the questions that those students were asked to consider. I then switched the treatment group with the comparison class for unit two on forces and acceleration to evaluate if the treatment had similar results for them. This occurred during the first three months of the school year 2021-2022.

I provided my students with numerous exit ticket formative assessments to gauge their understanding and attitudes. Likert scale items were used in addition to muddiest point, minute paper or one-sentence summary assessment strategies (Angelo & Cross, 1993). Along the way I kept a reflective journal of my thoughts and observations as to the impact of this curriculum change on myself as an educator.

Based upon our final master schedule at my school this past year, I had two sections of physics as part of my action research. Initially, one was the treatment group and the other the comparison group. These were switched for unit two in early November. Approximately twenty students were assigned to each class and were asked to participate in my study. A pre- and post- test was utilized for each class and for the two units of the study.

All students were asked to complete exit tickets and student surveys. One strategy utilized was to place survey questions at the end of homework assignments so that students believed that it was just a normal part of their task and that they became familiar with completing these questions. I reported the survey results to the class in a similar fashion to reviewing homework questions. It was my hope that students observed that I valued their opinions and made changes to improve the course based upon their feedback.

For pre- and post-test results I utilized a spreadsheet to compile student averages and create a box and whiskers plot for each unit test. I felt that this would effectively display student growth and average normalized gain. Student survey results were displayed using bar charts that correspond to answer choices from Likert scale questions or other ranking tasks to analyze student attitudes. The tests and surveys were completed on paper and scanned and filed electronically for convenient long-term access.

Smaller groups of randomly selected students from a population of convenience (having indicated that they were available for a meeting) were interviewed during seminar to gauge their understanding of concepts and attitudes toward the class. These results were analyzed for trends and reported in narrative format. Additionally, my perceptions and thoughts were recorded and analyzed to seek trends, compare early in the school year with four months later, and reflect upon the value of my action research project.

Table 1: Triangulation matrix for action research.

| Instrument: | Unit Pre- & Post-Tests | Exit Tickets | Student Surveys | Student Interviews | Teacher Reflections |
|---|---|---|---|---|---|
| Impact of a balanced combination of conceptual and mathematical practice problems | X | X | X | X | |
| Student comprehension improvement | X | X | X | X | |
| Student attitudes | | X | X | X | |
| Impact upon myself as an educator | | | X | X | X |

Out of a possibility of 22 points on the first test (see Appendix B), 11 points, or half of the test, were conceptual in nature, four were a combination of conceptual and mathematical, and the remaining seven points were awarded for mathematical problem solving. Any additional gains in the treatment group could be attributable to the questions that those students were asked to consider during the “Explain” portion of our class.

The unit one pre-test was given to students during the block-scheduled classes on Wednesday, September 1, and Thursday, September 2, within a 30-minute time frame. Students were told to use their “instincts and previous knowledge” to answer the questions, simply try their best, and that I would award them ten points out of ten as a quiz grade for answering every question. Instruction on kinematic concepts for my treatment class, and kinematic equations for my comparison class began on the same days. Before this class, we had not begun studying physics as we were engaged with the review of measurement, significant figures, and trigonometry.

After 16 classes, the post-test was given to my students on Wednesday, October 27, and Thursday, October 28. There were 17 students in my treatment class that took both tests, which included ten juniors and seven seniors. In addition, 20 students in my comparison class took both tests, one sophomore (enrolled in pre-calculus), 18 juniors and one senior. A total of three students that did not take both tests were excluded from the study. No interruptions, such as fire drills, occurred during the test periods. Four of the 17 students from the treatment class, and three of the 20 students in the comparison class had not quite completed the post-test at the end of the class period and were not granted any additional time.

The unit two pre-test (see Appendix C) was given to my students during the block-scheduled classes on Tuesday, November 2, and Wednesday, November 3, within the same conditions as set forth by the earlier unit one pre-test. Instruction on the concepts of Newton's Laws for my treatment class and using Newton's Laws with my comparison class began on the same days.

After eight classes, the post-test was given to my students in the comparison class on Wednesday, November 24, just before Thanksgiving break, and the following Monday, November 29, for students in my treatment class. All 19 students in my comparison class took both the pre- and post-tests. In my treatment class, 20 of the 21 students took both tests. All my students were able to complete the 23-point test during the time allotted. On the unit two test, ten points represented conceptual questions and the remaining 13 for mathematical problem solving. The lowest scoring student in my treatment class had moved to a new school during this unit of study. This fact, in addition to having Thanksgiving break between the two groups taking the post-test were issues that I could not control in my study.

The first student survey instrument (see Appendix D) was utilized after the first quarter grades were finalized and the first unit test was completed. Students in the treatment class received the survey as written. Students in the comparison class were asked modified questions 20 through 23 or 26 as those pertained to students in the concepts-first section. During the second iteration of this survey, the treatment and comparison classes were switched, and groups were given the appropriate corresponding survey.

I chose to include statements and questions that would help to capture student background, attitudes, performance, and engagement. This 30-item survey would help to answer all three of my action research sub-questions. Students volunteered to offer their feedback on the survey by placing a line along a continuum from thumbs down to thumbs up. I had been including two formative assessment items on student homework this year to help familiarize students with this survey type, in addition to a “Muddiest Point” question.

To analyze the data, I measured along the line to gauge the student responses as a distance reported between zero and ten centimeters. I then created a bar chart of the items that I wanted to highlight in my capstone action research project.

The second instrument was a follow-up set of interview questions. Students that had agreed to meet for an interview were randomly chosen from the population of convenience to answer these questions. Responses were analyzed for trends and reported as a percentage of the total respondents that had a similar statement.

The unit tests, student survey, and student interview instruments were created collaboratively and/or distributed for professional feedback from colleagues and professors to help insure validity. In addition, triangulation was utilized in this study to determine if the treatment’s effect was identified with multiple tools.

# DATA AND ANALYSIS

## Results

Using a pre- and post-test for the first unit of study in my physics classes, I have tracked the improvement in student's scores as a whole class and looked at sub-groups of students by gender, incoming GPA and PARCC math test score to determine if there was an outlying impact on any of these populations. Normalized gain <g> was calculated for each group as all the data were in matched pairs.

Initially, I examined whole class data and found that <g> was 0.54 (*N*=17) for the treatment class and 0.43 (*N*=20) for the comparison class, both medium gains (Hake, 1998). The normalized gain was calculated by taking the class average of the post-test, minus the class average of the pre-test, and dividing by the difference between 100 and the class average on the pre-test.

<g> = (class average post - class average pre) / (100 - class average pre)

The mean in the treatment class rose from 49% to 77% and the median student score changed from 50% to 77%. In the comparison group, the mean rose from 45% to 69% and the median student score changed from 45% to77%. It was the difference between the post-test mean of 69% and the median of 77% in the comparison group that led me to investigate further.

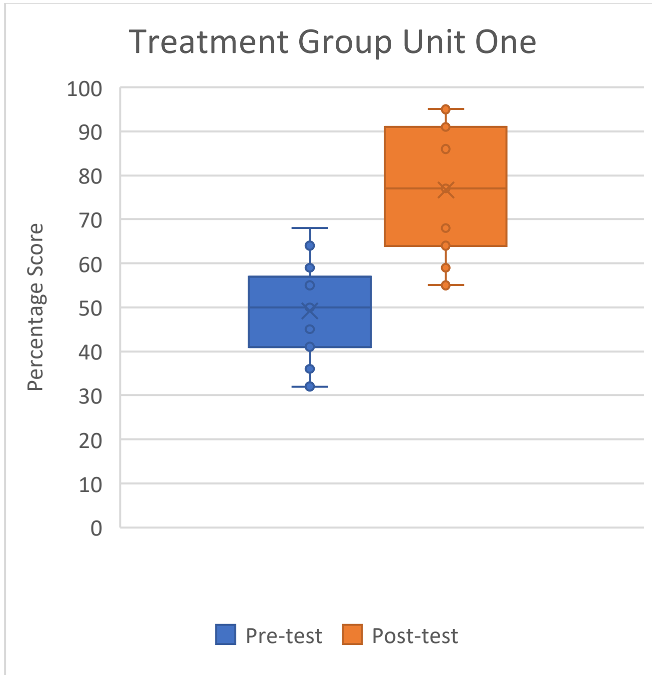


Figure 1. Treatment Group student scores on the unit one pre- and post-test (*N*=17).


Figure 2. Comparison Group student scores on the unit one pre- and post-test (*N*=20). Notice the X marking the mean was considerably lower than the median line on the comparison group post-test.

My student GPA data and PARCC math test score data were incomplete, so I decided to look at gender as it related to performance in each of the classes. The median student in the comparison group had the same score as the median student in the treatment class. However, some factor was bringing the mean down in the comparison group. I discovered that four female students, representing 20% of the class, were performing quite poorly with the more mathematical approach and lowering the average. These were the exact students that I had in mind when I first considered this research project and my desire to correct the concern that I have about students losing track of the concepts when being overwhelmed by equation problem solving.

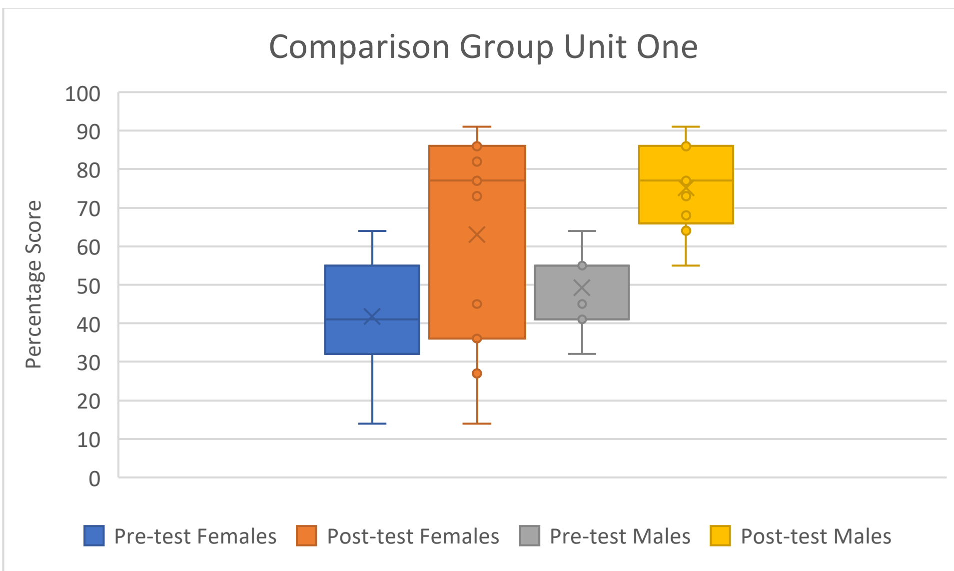


Figure 3. Student scores on the unit one pre- and post-test (*N*=20) for the comparison group. Females (*n*=11) and males (*n*=9) were disaggregated which results in easily observing that some of the young women were not performing very well.

Normalized gain was <g> = 0.37 for females and <g> = 0.51 for males, both medium gains. The average on the pre-test was 42% for females and 49% for males, where on the post-test it was 63% for females and 75% for males. One of the four females in the comparison group scored below her pre-test score. According to research by Miller et al. (2010), it was inconclusive on whether a loss such as this "represents actual conceptual losses, or result from correct guesses on the pre-test that, by chance, became incorrect on the post-test." However, eleven of the 22 points on the unit one test were awarded for student constructed responses rather than multiple choice. Nonetheless, I found it worrisome that a student fared so poorly, and having discovered this through data analysis, redoubled my efforts to assist her and other struggling students.

In examining the treatment class using the same lens, I found the opposite variation. Normalized gain was <g> = 0.61 for females and <g> = 0.46 for males, both medium gains. The average on the pre-test was 50% for females and 48% for males, where on the post-test it was 81% for females and 72% for males. Given similar starting points, the females were able to thrive in the concepts-first classroom and still perform very well on the mathematical equation problem-solving questions too.

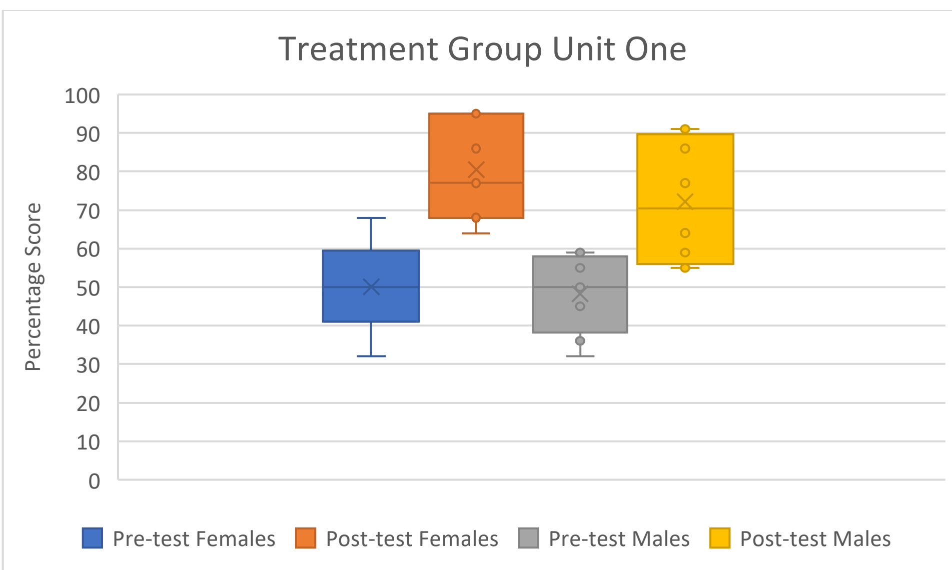


Figure 4. Student scores on the unit one pre- and post-test (*N*=17). Females (*n*=9) and males (*n*=8) were disaggregated. It was a little less obvious here that the males were not performing as well as the females, as their gains were smaller.

The number and type of questions that were asked of each group were manipulated through the various days of class when we were in the "Explain" phase of our 5E instructional model. During unit one there was about an 80-20% split between the types of questions that I asked my students to consider: either conceptual or mathematical problem solving. After determining my findings for the original comparison class, I decided to change the percentage for the new comparison class to about 50-50%. This was in realization that switching to a 20-80% split might be detrimental to my student's comprehension.

Table 2: Questions asked in treatment and comparison classes.

| Instrument: | Conceptual | Mathematical | Total |
|---|---|---|---|
| Unit One Treatment Class A2 | 118 (76%) | 38 (24%) | 156 |
| Unit One Comparison Class B4 | 12 (20%) | 49 (80%) | 61 |
| Unit Two Treatment Class B4 | 54 (83%) | 11 (17%) | 65 |
| Unit Two Comparison Class A2 | 15 (52%) | 14 (48%) | 29 |

Much more difficult to control was the type and number of student questions that were asked during discourse concerning the problems that I asked students to solve. Specific students were very adept at asking conceptual questions during a particular mathematical problem-solving session, which more than likely brought the necessary balance to the lesson. It was this exact type of balance that I sought to find, so it became a natural fit for my class experience. Additionally, the number of questions asked in the comparison group for each unit turned out to be roughly half that of the treatment group. This is due to the fact that the mathematical problem solving took much more class time than knocking out many conceptual questions in a burst between “punctuated lectures” and the use of the identically named classroom assessment technique (Angelo & Cross, 1993).

In examining student attitudes and engagement, a few results were on average significantly different between the concepts-first treatment class and the mathematical problem-solving class. This survey was given to students at the end of October as the first quarter had ended and grades were finalized. First, I was amazed at the low number of students that reported that they had met their first quarter grade goal. In the concepts-first class only four students (22%) out of a total of 18 reported that they had met their goal. The class average for the final first-quarter grade was an 89.1%. All but one student indicated that their goal was to earn an A; however, even students that earned an A- did not consider having met their goal. Students seemed to be under the impression that only an A is acceptable, rather than the true meaning of the grade which is “excellent.”

The comparison class was slightly more realistic where two students out of 21 indicated that their goal was a B and the remaining 19 wanted to shoot for an A. The results turned out that seven students (33%) met their first-quarter grade goal including the two that had a B as a goal and five that earned an A-, A or A+. The average in this class was 86.4%, which was slightly lower than in the concept-first class. There were four students that earned a C for the quarter and all of them were in this section.

Students in the concepts-first treatment class reported a lower average score in agreement with looking forward to attending physics class, interested in the activities we were doing, being engaged in class, and that class was helpful in improving their mathematical problem solving.

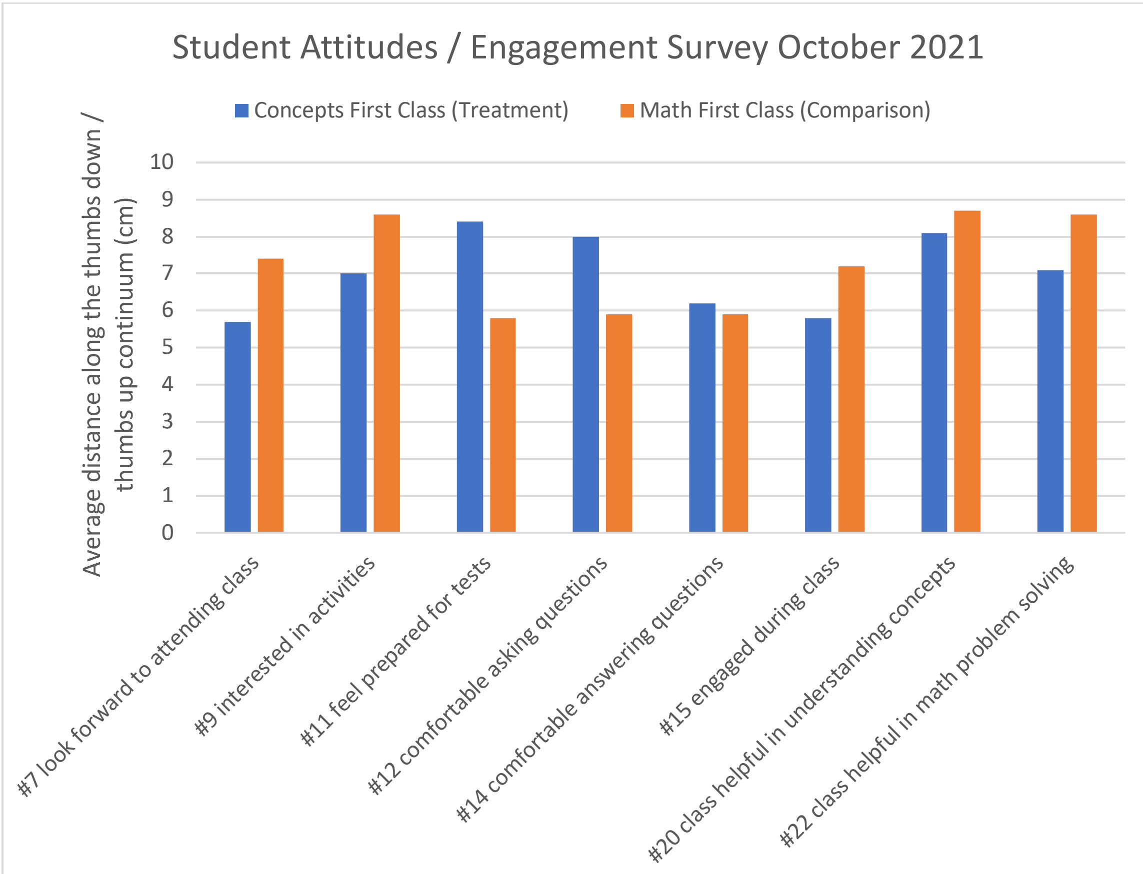

Figure 5. Student Attitudes / Engagement Survey results at the end of unit one. Larger average distances equate to more positive responses.

During subsequent student interviews, students were randomly chosen from a population of convenience. Four treatment-class students looked over the results from the survey in the figure above and indicated that “class can be boring” or “I tend to zone out when going over the concepts” as reasons that the students may be less engaged or not looking forward to coming to class. There was also the perception that they needed more help with mathematical problem solving and that we were spending too much time on conceptual understanding. Students were reminded that they had larger gains compared to the comparison class and the four agreed with the statement that knowing the concepts first before trying to solve mathematical problems was beneficial. This may also help explain why students generally reported more in agreement with feeling prepared for tests and comfortable asking the teacher questions in class.

Next, a group of four comparison class students examined the same figure above and two of the four indicated that they were less prepared for the tests because they did not understand the math. They mentioned “not even knowing where to start asking questions” or that “the math equations were so confusing.” Students agreed that the activities in class were generally interesting and more fun than working out additional math problems.

During unit two on forces and acceleration, students started with less comprehension, knowledge and skills, or perhaps more misconceptions, or all of the above. However, excellent gains were made in both of my classes.

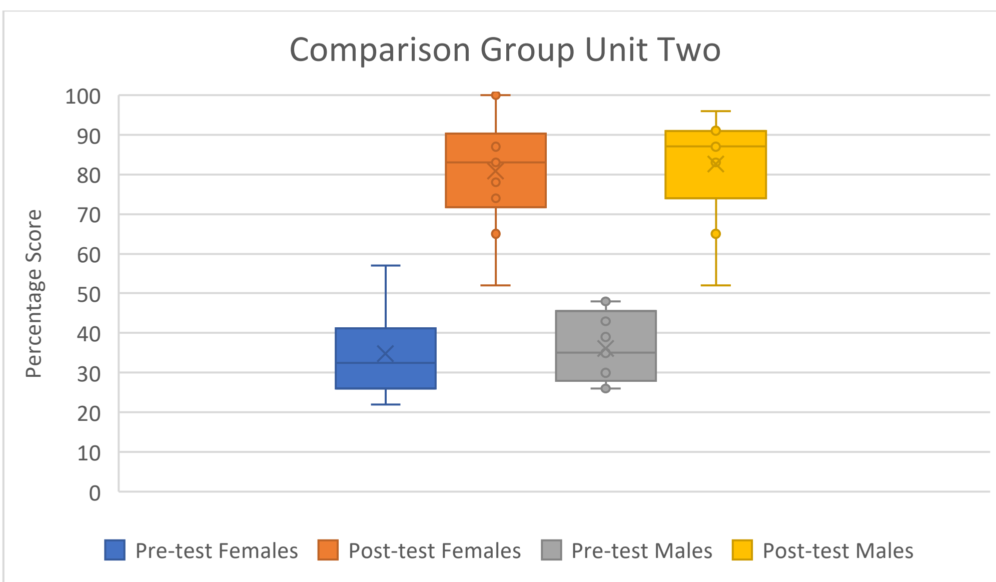


Figure 6. Student scores on the unit two pre- and post-test ($N$=19) for the comparison group. Females ($n$=10) and males ($n$=9) were disaggregated.

Normalized gain was <g> = 0.71 for females and <g> = 0.73 for males, both high gains. The average on the pre-test was 34.8% for females and 36.1% for males, where the post-test scores were 80.9% for females and 82.6% for males. This group worked through a roughly even 50-50% split of conceptual and mathematical problem-solving questions, and this produced a very desirable outcome.

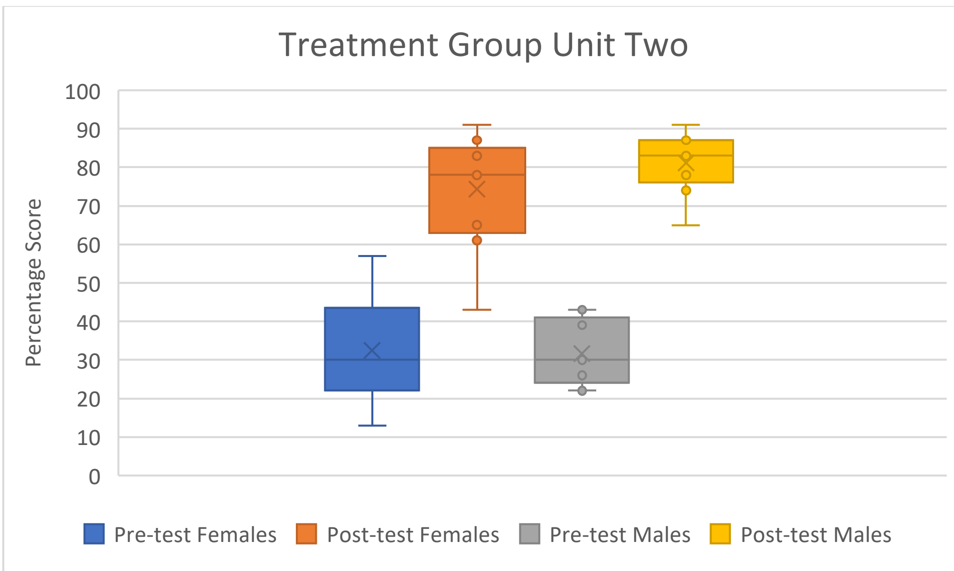


Figure 7. Student scores on the unit two pre- and post-test (*N*=18) for the treatment group. Females (*n*=9) and males (*n*=9) were disaggregated.

In the treatment class for unit two, normalized gain was <g> = 0.62 for females and <g> = 0.72 for males, both high gains. The average on the pre-test was 32.4% for females and 31.7% for males, where the post-test scores were 74.3% for females and 81.2% for males. This group worked through a roughly 80-20% split of conceptual to mathematical problem-solving questions which was the reverse of what they had been asked to tackle for unit one. One note was that the lowest scoring female of the class moved back to the states during this unit. However, the other three females that scored quite poorly in unit one, made good gains in unit two with the more conceptual approach.

# CLAIM, EVIDENCE AND REASONING

## Claims From the Study

The claim that a balance of about half conceptual problems followed by half mathematical problem solving during the "Explain" portion of the 5E instructional model would result in the greatest improvement in student understanding in a unit of physics, is supported by my findings. This was the focus topic of my action research project and unit tests, numerous exit tickets, student surveys and student interviews were utilized to suggest this assertion is true. The data supported the claim because students needed a strong conceptual foundation before they made sense of a numerical answer. This was especially true if students were then asked to change a value in a mathematical problem, resolve the problem, and write about the reason that the new solution was logical.

My first sub-question concerned how well students improved in the comprehension of the information presented in the two units of study. The balance of conceptual and mathematical problems was the reason for student improvement in the second unit of physics we studied this past school year. Both the concepts first treatment group, with about 80% conceptual and 20% mathematical problem-solving questions, and the balanced comparison group, with about 50% of each type of question, demonstrated high normalized gains. Previously, the comparison group which was asked about 80% mathematical followed by about 20% conceptual questions, only had medium gains. The data suggested that it was important to demonstrate concepts and have students "Explore" the topic before working on complex mathematical problems in the "Explain" portion of class, where students have the tendency to lose track of the bigger picture.

Students agreed that having a working knowledge of physics concepts was important before they could make sense of answers to mathematical practice problems. In a whole-class session of member checking, I determined that 15 students (88%) in the original treatment class agreed that concepts-first instruction improved their level of conceptual understanding, where 20 students (95%) from the comparison class agreed. This original comparison class switched to become the treatment class for unit two and perhaps were more sensitive to the difference of instruction and appreciated the depth of knowledge of the concept before digging into mathematical problem solving. Additionally, 17 students (81%) in the original comparison class agreed that previous knowledge of the concepts was helpful in determining if an answer to a practice problem seemed reasonable. The remaining four students felt that we should have continued with a more mathematical approach as that was where they considered their difficulties to exist. This data was important as it demonstrated that students had generally positive attitudes toward the concepts-first instructional sequence. Determining student attitudes during these units of study was my second sub-question of my project. The reasoning once again was in being able to explain why an answer to a mathematical practice problem made sense. Students enjoyed building upon their conceptual knowledge with correct answers to problems that gave them confidence in their abilities and allowed them to score higher on tests in their quest toward an excellent grade in the class. According to the student attitudes and engagement survey data, there was a high level of agreement that the class was helpful in understanding concepts and in solving math problems.

My final sub-question for this action-research project was to determine how teaching these units impacted me as an educator. It was my job to best determine the balance between conceptual knowledge and mathematical practice problems that I have my students consider for each unit of study. Some ideas in physics were more of a part of students' prior knowledge than others, so would not need as much of a conceptual framework. However, students may not be as adept at the mathematical problems that are associated with each unit. In my teacher reflections, I commented many times about how students wanted to ask how a math problem could be solved. After helping them through it, we discussed changing a value and solved the problem again. Then I asked the student to summarize the concept, but in some cases they could not. I felt that this was true due to students lacking a big picture viewpoint of the topic, as they remained stuck in the smaller details of the problem at hand. Some students also remained skeptical about the need for conceptual knowledge as they felt their only difficulties were in solving math problems.

## Implications of Action Research on the Author

Early in my three-decade long teaching career, I gave students unit pre-tests. I consistently determined that students understood very little of the unit content and skills, so I dropped using pre-tests as I considered them a waste of precious instructional time. My intention was to determine if I could skip over any of the unit content to save some time, but continuously found that I could not, as students demonstrated little previous knowledge.

However, I have found that I was utilizing pre-tests incorrectly as I did not pair the pre-test with the post-test to complete useful data analysis to look at group and individual gains. This was the power of the pre- and post-test combination and I have learned that using them, especially early in the year, can provide excellent insights to your students' needs. Without the proper data analysis students can slip through the cracks before you can help them make the greatest gains by differentiating instruction to best meet their needs.

In the future, I would continue to utilize pre- and post-tests to analyze student gains. I wrote in my teacher reflections about my renewed confidence in the importance of this strategy. Additionally, I would continue to look for the best combination and sequence of conceptual problems and mathematical practice that helped students to make the largest improvements in their knowledge and skills. Focused collaboration with other physics teachers should remain an important part of a weekly routine to share experiences and best practices. Monitoring student attitudes and watching for being "tuned out" or bored with repetition would also be important.

## Value of the Study and Consideration for Future Research

Through my action research I set out to find the ideal balance between conceptual physics understanding and mathematical problem solving in my classroom. My initial findings pointed toward improved test scores for female students in a concepts first physics classroom. However, males may have done better in a more mathematical problem-solving environment. This result was somewhat similar to the analysis conducted by Huffman (1997).

The question of whether males can grasp the concepts better through the use of mathematical problem solving or was it through the various other activities such as the modeling investigations, and guided inquiry laboratories, would be interesting to examine further. Perhaps even an extreme situation, such as learning in a gender-segregated environment, could be studied at a private school to learn more about gender differences in acquiring physics conceptual knowledge, if any exist.

This study could be extended to subsequent units on 1) work, energy, & power; 2) momentum; 3) circular motion; 4) electricity & magnetism; and 5) waves. A teacher/researcher could continue tweaking the number of conceptual problems that are asked of students in the “Explain” portion of the 5E instructional model before working on mathematical practice problems. With an increased awareness and knowledge of the balance between concepts-first instruction and mathematical problem solving, reflection could continue upon what would best serve students in conceptual and mathematical mastery of physics. The quantity of each type of practice question that results in maximizing student understanding, may differ by a student’s gender, the particular topic in physics, the background students bring to the discussion, among other variables.

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APPENDICES

# APPENDIX A

## INSTITUTIONAL REVIEW BOARD EXEMPTION

An exemption by Montana State University's Institutional Review Board was not obtained, initially due to personnel changes at my school, followed by personnel changes at DoDEA, and finally due to preparing for policy changes at DoDEA headquarters where it was stated that they were unable to support the research at this time.

## APPENDIX B

PHYSICS – UNIT 01 – ONE DIMENSIONAL MOTION TEST

Name ______________________________________________________ Period _____

**Physics – Unit 01 – One Dimensional Motion Test**

*Write the letter that best completes the statement or answers the question on the line at the left.*

________1. Which quantity has both magnitude and direction?
A. energy B. scalar C. unit D. vector

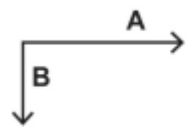
________2. Scarlett is analyzing a position-time graph of an accelerating train. Which quantity can be found by measuring the slope of a line that is tangent to a point on the graph?
A. acceleration
B. displacement
C. average velocity
D. instantaneous velocity

________3. The average velocity and time of motion for three objects are recorded.
I. $v_{avg} = +2.0$ m/s, $\Delta t = 2.0$ s
II. $v_{avg} = +3.0$ m/s, $\Delta t = 2.0$ s
III. $v_{avg} = -3.0$ m/s, $\Delta t = 3.0$ s
Which option ranks the magnitude of the displacement of these objects in order from the largest to smallest displacement?
*Note: Assume each item has zero initial displacement.*
A. I, II, III B. II, III, I C. II, I, III D. III, II, I

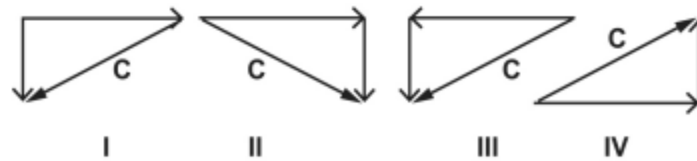
________4. A car's velocity is positive and its acceleration is negative. Which statement describes the car's motion?
A. The car is speeding up.
B. The car is slowing down.
C. The car is remaining at rest.
D. The car is traveling at constant speed.

________5. Which statement(s) describes the motion of a ball right after it drops onto a vertical spring? Mark ALL that apply.
A. The acceleration of the ball decreases as the spring compresses.
B. The acceleration of the ball remains the same as the spring compresses.
C. The acceleration of the ball increases as the spring compresses.
D. The velocity of the ball changes from positive to negative as the spring compresses.
E. The velocity of the ball remains the same as the spring compresses.
F. The velocity of the ball decreases as the spring compresses.
G. The velocity of the ball increases as the spring compresses.

________6. The diagrams show vectors.




Which diagram represents the vector addition
C = A + B?
A. I
B. II
C. III
D. IV




________7. Which scenario describes a change in the velocity of a ball?
A. a ball staying still on a table
B. a ball rolling on a table at a constant speed
C. a ball attached to a string and dragged on a table at a constant speed
D. a ball attached to a string and spun around at a constant speed

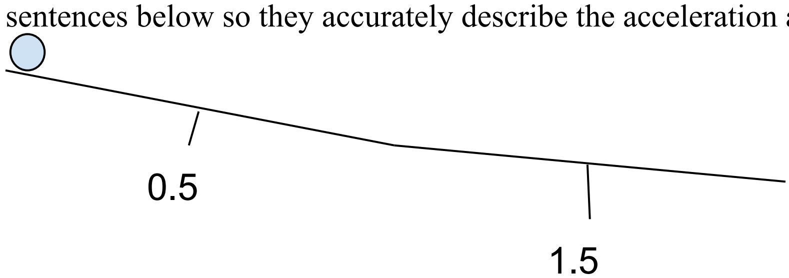
*Read each statement. Write your answer below.*
8. A runner drops her phone as she is running at a constant speed of 3 miles per hour from point A to point B in a park. Describe the motion of the phone as it is observed by someone sitting on a bench at the park. Please support your answer with an illustration.

9. A woman and her dog enter a park at the south gate. The woman walks straight through the park. The dog has no leash on and wanders around the park but ends up with the woman when she leaves the north gate. Compare the displacement of the dog and the woman. Compare the distance traveled for the dog and the woman.

10. A motorized scooter starts from rest and accelerates for 4 seconds at 2 m/s$^2$. Calculate the **average velocity** of the scooter for the interval 0–4 seconds.

11. A cyclist starts from rest and accelerates for 5 seconds at 3 m/s$^2$. After the first 5 seconds, the cyclist continues at a constant speed for 5 more seconds. Explain during which interval the cyclist's average acceleration is greater, 4.0–5.0 s or 5.0–6.0 s.

12. A marble is rolled down a ramp. The ramp has a slope of 0.2 for the first meter and then 0.1 for the second meter. Circle the correct word in each parenthesis to complete the sentences below so they accurately describe the acceleration and velocity of the marble.

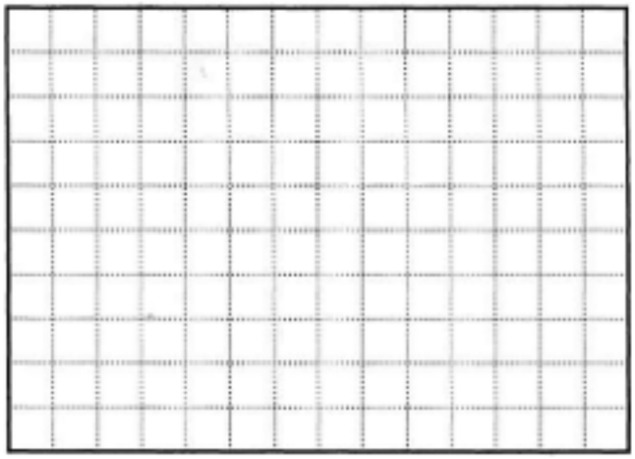



At 0.5 m the marble's velocity would be **(higher / lower / the same)** compared to the velocity when the marble is at 1.5 m.

At 0.5 m the acceleration would be **(higher / lower / the same)** compared to the acceleration at 1.5 m.

At the 0.5 m mark the marble's velocity would be **(increasing / decreasing)** at the/a **(same / lower / higher)** rate when compared to the 1.5 m mark.

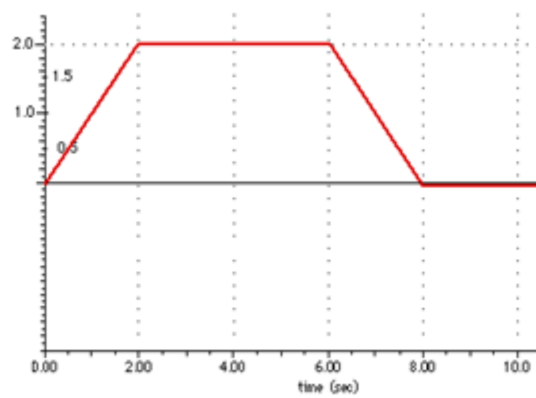
13. Construct a graph of position versus time for the motion of a dog, using the data in the table at right. Include labels and units.

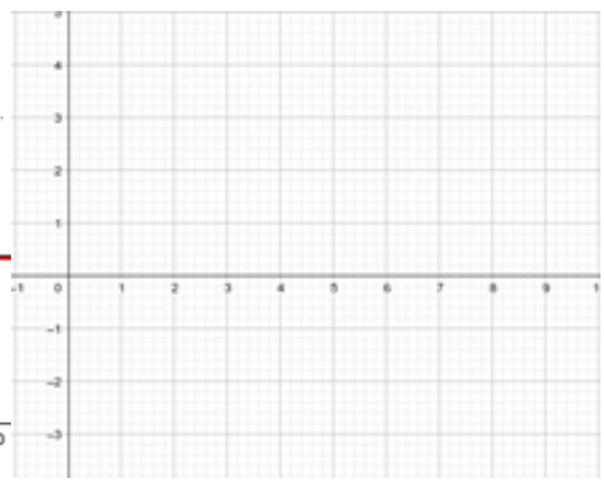


| Time (s) | Displacement (m) |
|---|---|
| 0.0 | 0.0 |
| 2.0 | 1.0 |
| 4.0 | 2.0 |
| 6.0 | 3.0 |
| 8.0 | 4.0 |
| 10.0 | 5.0 |

Explain how the graph indicates that the dog is moving at a constant speed.

14. Draw a numerically accurate velocity/time graph from the following position/time graph:



15. At the speedway a stock car has a constant velocity of 98 m/s on the front straightaway. The driver applies the brakes as the car approaches a crash which causes the car to slow at a rate of 4 m/s$^2$. When the driver passes the crash, the stock car has a speed of 82 m/s. How far has the car traveled while breaking?

# APPENDIX C

## PHYSICS – UNIT 02 – FORCES AND ACCELERATION TEST

Name ______________________________________________________ Period _____

**Physics – Unit 02 – Forces and Acceleration Test**

Multiple Choice: Write on the line at the left of each statement the letter(s) that best answer each question.

________1. Which statement is true when the same force is applied to two objects of different masses?
A. Both objects will accelerate at the same rate and in the same direction.
B. Both objects will accelerate at the same rate but in different directions.
C. The object with greater mass will experience a greater acceleration than the object with less mass.
D. The object with greater mass will experience a smaller acceleration than the object with less mass.

________2. Which statement is always true about the normal force?
A. It is a scalar quantity.
B. It equals Fg in magnitude.
C. It points vertically upward.
D. It acts perpendicularly to a surface.

________3. A hammer drives a nail into a piece of wood. Which statement describes an action-reaction pair in this situation?
A. The hammer exerts a force on the nail; the wood exerts a force on the nail.
B. The hammer exerts a force on the nail; the nail exerts a force on the hammer.
C. The nail exerts a force on the wood; the hammer exerts a force on the nail.
D. The nail exerts a force on the hammer; the hammer exerts a force on the wood

________4. Which of the following statements is/are true about the movement of an object when it experiences a positive net force? **Mark ALL that apply.**
A. the object will accelerate
B. the object will move at a constant velocity
C. the object will not be moving
D. the object will move in the direction of the net force
E. the object will move toward the center of the earth due to the force of gravity
F. the object will move in the direction of the frictional force

_______5. A sled slides down a hill, reaches the level surface and eventually comes to a stop. The fact that the sled ultimately stops is best explained by which of the following?
A. the natural tendency of any object is to ultimately stop
B. the presence of inertia causes it to stop
C. the presence of an unbalanced force (e.g., friction) can cause a moving object to stop
D. an unbalanced force would be required to keep the sled moving forward at a constant speed

________6. If you were in a spaceship and fired a cannonball into frictionless space, which of the following best describes the amount of force needed to keep the cannonball in motion?
A. equal to the weight of the cannonball
B. zero, since no force is necessary to keep an object moving
C. equal to the force with which it was fired
D. more than the force with which it was fired
E. less than the force with which it was fired

________7. For the following situation, identify the force(s) which are exerted upon the object. A person is standing on the ground. **Mark ALL that apply.**

| | | |
|---|---|---|
| A. Air Resistance | B. Force of Friction | C. Force due to Gravity |
| D. Magnetic Force | E. Normal Force | F. Spring Force |
| G. Tension | H. Applied Force | |

________8. A skydiver steps off a plane at an altitude of 5000 m. As the skydiver falls, her speed steadily increases. This causes the air resistance force to _______ and the acceleration to _______.
A. decrease, decrease
B. decrease, increase
C. decrease, stay the same
D. stay the same, increase
E. stay the same, decrease
F. increase, increase
G. increase, decrease
H. increase, stay the same

________9. Earth is held in orbit by the force of gravity between the more massive Sun and Earth. The force of Sun on Earth is _______ the force of Earth on Sun; the resulting acceleration of Sun is _______ the acceleration of Earth.
A. greater than, greater than
B. greater than, less than
C. greater than, equal to
D. equal to, equal to
E. equal to, greater than
F. equal to, less than
G. less than, less than
H. less than, greater than
I. less than, equal to

________10. If you push a crate across the floor with a force of 100 N and it slides at constant velocity, what can you say about the force of friction between the crate and the floor?
A. it is less than 100 N
B. it is equal to 100 N
C. it is more than 100 N
D. it is more than 200 N

________11. What is the net force of a 200 kg crate sitting at rest on a factory floor?
A. zero
B. 200 kg
C. 2000 N
D. None of these

________12. The weight of a 2 kilogram bag of grapes is
A. about 10 N
B. about 20 N
C. about 30 N
D.more than 30 N

________13. If you pull horizontally on a 50 kg crate with a force of 500 N, and the friction force on the crate is 250 N, acceleration of the crate is
A. zero
B. 2 $m/s^2$
C. 4 $m/s^2$
D. 5 $m/s^2$

**PLEASE SHOW ALL WORK ON THE FOLLOWING PROBLEMS**
14. A wagon having a mass of 91 kg is accelerated across a level road at 0.97 $m/s^2$. Calculate the net force that acts on the wagon horizontally.

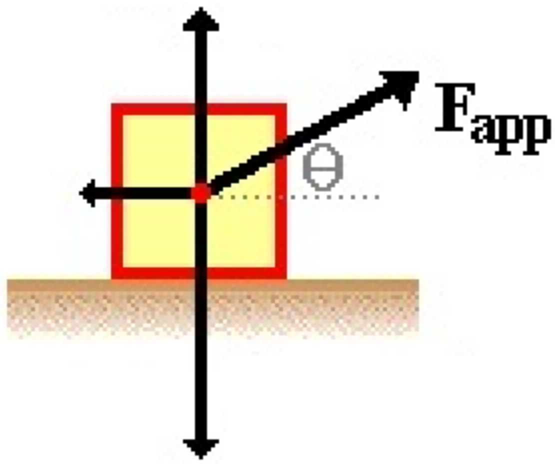
15. A bucket of water weighing 110 N is being lifted by a person pulling upward on a rope with a force of 130N.

A. What is the net force on the bucket?

B. Calculate the mass of the bucket.

C. Calculate the acceleration of the bucket

16. Consider the situation shown below. A 28.5 N force is applied at a 30.° angle to the horizontal to accelerate a 6.5 kg box across a rough surface. The force of friction is 10.9 N. **Label the forces on the diagram below.**




A.) Solve for $F_{grav}$: ______________

B.) Solve for $F_{app}$ vertical: _________________

C.) Solve for $F_{norm}$: _____________________

D.) Solve for $F_{app}$ horizontal: _________________

E.) Solve for $F_{net}$: ___________________

F.) Solve for acceleration: ________________

# APPENDIX D

ATTITUDES, PERFORMANCE AND ENGAGEMENT SURVEY

Concepts-First Instruction Attitudes, Performance and Engagement Survey

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

Name: ________________________________ Class Section: _______________

Gender: _________ First Quarter Physics Class Average: __________

Met First Quarter grade goal? Y / N Percentage Grade on Unit 01 Test: __________

Please rate your agreement with the following statements by placing a line on the continuum from thumbs down to thumbs up:

7.) I look forward to attending physics class.

8.) I come to physics class prepared with my homework complete.

9.) I find the activities we do in physics to be interesting.

10.) What activity do you remember being particularly interesting? Why?

11.) I feel prepared for quizzes and test in physics.

12.) I feel comfortable asking my teacher questions in physics.

13.) Can you give an example of when you asked a question?

14.) I feel comfortable answering questions in physics.

15.) I feel engaged during physics class.

16.) Why did you answer the way you did in question 15 above?

17.) I work to the best of my ability in physics.

18. ) I am satisfied with my performance in physics.

19.) It is important to me to do well in physics.

Please indicate your answer to the following questions by placing a line on the continuum from thumbs down to thumbs up:
20.) Did the use of concepts-first instruction in your physics class improve your level of conceptual understanding in this course?

21.) Why did you answer the way you did in question 20 above?

22.) Did the use of concepts-first instruction in your physics class improve your level of mathematical problem solving in this course?

23.) Why did you answer the way you did in question 22 above?

24.) How well did you improve during unit 01 compared to what you understood on the unit 01 pretest?

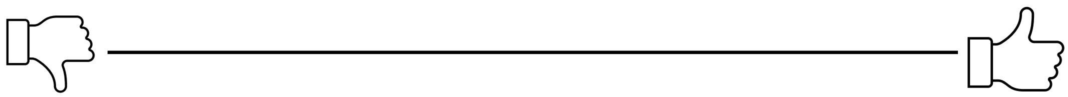
25.) What was your level of engagement as measured by time spent in class or away from class invested in physics?

26.) Did the use of concepts-first instruction in your physics class improve your level of engagement in this course?

27.) Did you find that the online instructional review videos helped improve your conceptual understanding of the physics topics?

28.) Did you find that the online instructional review videos helped improve your mathematical problem-solving abilities using the physics equations?

29.) What is your level of agreement to be part of a randomly selected interview group during class next week?



30.) Do you have any other feedback concerning this class?

# APPENDIX E

## CONCEPTS-FIRST INSTRUCTION INTERVIEW QUESTIONS

Concepts-First Instruction Interview Questions

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

Thank you for agreeing to be interviewed. This is a follow-up investigating the use of concepts first physics instruction in our class. The questions pertain to how the use of concepts first physics instruction influenced your attitude, performance and engagement related to unit 01 in physics. The interview should take about 15 minutes and will become part of my data analysis for my research project.

Name of student: ____________________ Section: ______ Today's date: ____________

What were any positive outcomes to concepts-first physics instruction? Can you give me an example?

What were any negative outcomes to concepts-first physics instruction? Can you give me an example?

When we were learning about physics concepts using multiple choice or multiple/multiple choice questions, what was your level of engagement in answering the questions?

How did the concepts-first instruction help prepare you for understanding equation problem solving?

How much background have you had in equation problem solving? What grade and how well did you do?

How did the instructional style used affect your level of engagement?

Would you like to continue with concepts-first instruction or focus primarily on mathematical equation problems? Why?

What is your biggest motivator to learn physics? Why does this motivate you?

If you were the physics teacher, how would you change this course?

Thank you again for taking your time for this interview!