EVALUATING ASSESSMENT TOOLS FOR LEARNING

IN A HIGH SCHOOL AP PHYSICS CLASSROOM

by

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DEDICATION

My mother is my inspiration, my encouragement, and my best friend. She modeled the value of effective teaching, and I would not be here without her.

My husband is my support. Thank you.

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ABSTRACT

This research studies if the effect of two different assessment strategies, (1) Documented Problem Solutions and (2) Performance-Based Assessment, on physics exams. This study takes place in a High School AP Physics course that utilizes AP Classroom by College Board online as the source of the examination utilized to measure student outcomes.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

Context of the Study

My favorite class in high school was physics because the teacher was enthusiastic, the content was interesting, and the problems were fun to solve. One memory I recall was not understanding how to calculate projectile motion correctly, and I remember it as something I did not achieve. As a teacher who is new to teaching AP Physics at Nordhoff High School, my goal is to provide students with meaningful science experiences. In this study, I worked to support my students to solve problems by analyzing the steps and discussing the process to provide the foundation needed to retain the information and solve problems like projectile motion on the AP exam.

The previous physics teacher at Nordhoff High shared her observations regarding the difficulty of teaching AP Physics. There are often a handful of students that do not know the order of mathematical operations in the same classroom as students who take calculus. Not only do I have to teach physics at the college-level, but I will also teach basic mathematical processes. To ensure all students hit basic milestones to move forward. If students have an *"aha"* moment and really retain the information, then I can move forward in the coursework knowing students are ready to move forward working towards multistep problem solving in physics.

This leads me to the focus of this study; to facilitate students' development of problem-solving skills while improving their mathematical skills in preparation for an AP exam and college physics.

School Demographics

In a high school of 741 students, over 40% of the high school population was socioeconomically disadvantaged, 3% are English Learners, and almost 0.9% are homeless (California Dashboard, 2017). 40% of students are on free or reduced lunch, which is government subsidized based on family income. Forty percent of students were Hispanic, 54% were White/Caucasian, 0.4% were American Indian, 0.5% Filipino, 0.1% Pacific Islander, 0.5% African American, 2% Asian, and 2.3% were of two or more races (California Dashboard, 2017). This school population was still diverse and was evident in our school parking lot with student cars ranging from luxury to barely running. The demographics described here also reflect my AP Physics classroom. Of these 21 students, 19 students were White/Caucasian and two students were Asian Pacific or Vietnamese. This was the only elementary physics course at our school and was one of the smallest sized classes. There were students accepting college applications from private universities in the same setting as another student who was identified as homeless. The goal here is to find teaching strategies that serve all students in my classroom.

My goal as a physics teacher, is to give my students confidence that they can do physics. When we close our eyes and imagine a scientist, diversity is generally not the first thing that comes to mind. In a webinar last summer, I heard physics professors from the University of California at Riverside say the state of Texas requires high school students to take four years of science in order to be prepared to work for big technology and the industry in Texas (Haibo, 2021). If students pursue a physics degree, a door opens and there are options. Other science majors like biology may have to compete with students who did not make it into medical school. This is why I want to give my students the confidence that they can do physics.

The focus of this research is to help improve student achievement of the learning goals in my AP Physics classroom.

Focus Statement/Question

My focus question was, What teaching strategies based on assessments improve test scores for AP Physics students using College Board exams?

My sub-questions include the following:

1. Does *Documented Problem Solutions*, a classroom assessment technique (CAT), make a difference on student scores on the College Board AP Classroom summative exams?
2. Does formally assessing students' performance, in NGSS science and engineering practices, make a difference on student scores on College Board AP Classroom summative exams?

CHAPTER TWO

CONCEPTUAL FRAMEWORK

Assessments for Learning

In a high school science classroom, students often end a unit with one big test to assess how well the content was learned and retained. Students may go through notes and find key vocabulary or memorize key concepts before putting the notes away and taking the formal exam. This exam is graded and passed back, students compare grades, and the test ends up in the trash without looking back. The purpose of this research is to find a better way to use assessments that facilitate student learning.

Instead of a summative evaluation with little reflection, assessment could be formative with the goal of monitoring student learning while helping students learn. Some impacts of formative assessment may include (a) purposeful planning, (b) communication of learning goals and criteria for student success, and (c) continual evidence of student learning for reflection and adaptation (Moss & Brookhart, 2009). When formative assessment is intentional there may be the opportunity to optimize student learning.

Students benefit from continual and informative feedback while also being involved in the process (Ari, 2009; Black, 2002; Stiggins et al., 2005). If students only understand what the teacher's expectations are at the end of the unit and test, then they will not clearly understand what is expected in the learning process. Clear goals and criteria for success, outlined by assessments, can be motivating for some students to be successful (Moss & Brookhart, 2009). Assessment can be a tool for working towards those goals when the students have clear goals from instruction.

Instructional practices can utilize assessment as a tool for learning in order to achieve the outlined goals. According to Ari (2009), “if students are tested on material and successfully recall or recognize it, they will remember it better in the future than if they had not been tested and if you assess knowledge quite frequently, that in itself is a learning tool” (p. 203). Repetition can be used as a tool. The more students are exposed to the learning objectives in the clear format of assessment, the more likely they will be able to recall that content later. This method of frequent testing is informative feedback from the teacher that also involves students in the process, which is key to effective assessment (Ari, 2009; Black, 2002; Stiggins et al., 2005). Assessment can be an effective tool in the process of learning because it serves as a clear outline of learning goals, immediate feedback, and practice through application.

Pupils can assess themselves only when they have a sufficiently clear picture of the targets their learning is meant to attain (Black et al., 2004). When this is done, all assessment can be used for productive learning (Deeley, 2018). Through assessment, efficient feedback may motivate students in their work towards achieving learning goals (Ari, 2009). When students have clear expectations on learning goals, students will have the confidence that they can succeed, which can be motivating. And when testing is done effectively, it can have a positive effect on long-term retention regarding the learning objectives (Ari, 2009). This means that assessment can be used for learning and can empower students in the learning process.

Strategic Preparation for Assessments

Assessment can also be used, by the teacher, as a tool to improve instruction. For example, a teacher may implement a variety of strategies and reflect on the effectiveness of such strategies by reviewing student assessments to examine outcomes. According to Sandlin (2015), it is essential to outline instructional goals in order to draw more valid conclusions about instruction based on student performance data. This highlights the importance for clear instructional goals for the students and the importance of the teacher clearly outlining what is being assessed and what steps are necessary to be successful on these assessments.

Reflection of assessment results may be data-driven to find best practices that teach content effectively. The process of data-driven inquiry is executed by (1) first defining a goal for assessment, then (2) collecting evidence from students, (3) next analyzing that data, and (4) finally adjusting instructional practices (Sandlin, 2015). The first step in this data-driven research is to determine the learning goals and align those goals with instructional practices. The second step is to outline the strategies that will be implemented and compared in order to find best practices (Mertler, 2020).

Critical Thinking

Critical thinking facilitates mastery of learned content and science literacy because students step away from memorizing and step into analyzing, interpreting, and communicating the information at hand (Windshitl et al., 2018). When students are challenged to think critically, they are encouraged to struggle with the content in a way that allows them to think and grasp the concepts (Windshitl et al., 2018). In science education, required outcomes often include the demonstration of knowledge of key concepts and critical thinking (Ramlo, 2019). Critical thinking is the skill that science students apply while learning the curriculum, yet is often more difficult and subjective to assess (Ramlo, 2019). That is why Ramlo (2019) suggests utilizing a rubric to evaluate students' analytical skills that demonstrate critical thinking. Even though critical thinking may be subjective, it is essential for developing skills that are transferrable to other domains or career-oriented preparation. Students should be challenged to think critically about the content while also understanding the content. According to Ramlo, critical thinking has purpose and utilizes reflection during processes such as analysis, evaluation, and inference, while linking to metacognitive, which is knowing about one's own knowing. Therefore, logical conclusions can be drawn through critical thinking skills that evaluate supporting evidence or logical conclusions (Ramlo, 2019). This means that students who do critically think may grasp the concepts better.

Conceptual Understanding

According to Ramlo (2019) and Windschitl et al. (2018), there is a relationship between critical thinking and conceptual understanding, which are common learning outcomes. Students who are challenged with critical thinking opportunities while learning the concepts should be able to apply their knowledge to make sense of the world around them. For example, most students enter physics classes with misconceptions based on their experiences, but when students adjust their conceptual understanding to fit the concepts in the lesson, that is where learning occurs (Ramlo, 2019; Windschitl et al., 2018). If critical thinking is taught with conceptual understanding, then students will retain information because they have internalized the information and compared it to their background knowledge and experiences. They then fit the new knowledge into the puzzle of their understanding by adjusting or eliminating their misconceptions (Windschitl et al., 2018). An example of students' not learning is when their conceptual understanding does not change, or when the student only accepts the concepts that fit into their mental schemas, while disregarding the concepts that do not fit (Ramlo, 2019). This means that it is essential to elicit student ideas, compare those to what is being taught, address misconceptions, and then revise with new information to formulate a conceptual model that is accurate and applicable.

Strategies for Teaching Physics

According to Deeley (2018), a teacher's ability to reflect on their instruction is a central factor in their professional development, especially with the tasks of planning, executing and improving instruction to facilitate higher cognitive processes in class. The purpose of this study is to reflect on instruction in order to plan and improve instructional strategies for student success in assessment for Advanced Placement (AP) Physics.

High school physics' curriculum is very structured, and the strategies implemented are designed to assist students in understanding the physics concepts, thinking critically, and succeed in an AP assessment which is administered through College Board. Deeley (2018) suggests having students solve problems in different ways, learn from mistakes, frequently make figures and graphs, think out loud, describe expected results from experiments, draw conclusions from experiments, allow students to present different positions on an issue under debate, and first cover the verbal model followed by the mathematical model. These strategies suggested by Deeley (2018), offer an example of what students should be doing in the classroom. The next example provided by Kouz (2020), provides an example template for how instructional strategies may be organized. Kouz (2020) offers an approach teaching sciences in medical education which may be applicable in physics, namely: (a) first evaluate pre-knowledge, (b) highlight necessary content linked to the subject, (c) focus on necessary facts rather than giving too much information, (d) avoid content redundancy and establish coherence, (e) provide students with helpful notes, (f) connect the content across subjects, (g) and educate the teacher (2020). Gale (2015), suggests that simulations allow students to gather evidence of conceptual understanding. And Weaver (2018), emphasizes exploratory learning before students are taught the underlying concepts and procedures in order to engage the student in the content, and then elaborate and explain so that the student can relate to the information. These suggestions are all valid and point to the value of using two different strategies that utilize assessment as a tool for student success.

Strategies Tested in this Research.One assessment strategy is *Documented Problem Solutions*, a classroom assessment technique [CAT] by Angelo (1993), in which students document in writing or with audio recordings *how* to solve physics problems. Students record how they solve relevant physics problems, step-by-step, describing both their approach and their solution. According to Angelo, this method did improve students' test results in a college calculus class, so it may have the potential in assisting physics students' comprehension of mathematically based problem solving in AP Physics (1993).

The second assessment strategy is Performance-Based Assessment, which utilizes NGSS science and engineering practices in application is what is being tested. For example, students interpret and analyze data, design an investigation to test a hypothesis, and draw conclusions for a scenario regarding provided data tables. According to Frey (2018), Performance-Based Assessment includes one or more of the following

> First, performance-based assessment often involves high levels of interactivity or engagement with the testing task/item. Second, the result of performance-based assessment is usually the generation of a unique product or performance. The third and perhaps most defining element of performance-based assessment is the extent to which the testing task is contextualized in highly realistic scenarios. For tests composing one or more performance-based tasks, the measurement expectation is that the test takers will demonstrate their proficiency through tasks that are complex in nature and structured to mimic or replicate the real-life situations in which the skills of interest would be used or needed (p. 1235).

Ideally, a well-designed Performance-Based Assessment will combine all three of the conditions Frey explained. This allows students to show what they know through performance demonstrating their knowledge and skills in realistic scenarios. In other words, students individually use NGSS SEPs to solve problems, ask questions, and demonstrate their learning which mirrors the work done in my AP Physics class (NSTA Press, 2015).

CHAPTER THREE

METHODOLOGY

Demographics

The purpose of this study is to find tools that help my students retain information for learning physics. Two assessment strategies were implemented, and data was collected with tests and surveys. Student outcomes were analyzed to determine the efficacy of these two assessment strategies which are the sub questions of my focus question in this research.

This research was conducted with 21 students in my 6th period High School AP Physics class, an elementary physics course (December, 2021). Of these 21 students, 19 students are White/Caucasian and two students are Asian Pacific or Vietnamese. The students in this class have some of the highest GPA averages in the school and most of these students also take AP government and other high-level courses. These students are confident and speak out loud during classroom discussions. Furthermore, they engage readily with physics content in a variety of formats, and many have a background in calculus or are currently taking trigonometry. The students are eager to participate, get along with others, help each other, and ask questions. This is an ideal group of students for any teacher because these students are willing and ready to learn.

In this study, my intentions were to test various assessment tools and analyze the data collected to infer whether or not the assessment tool was a successful strategy for learning physics. The two tools included (1) Documented Problem Solutions and (2) Performance-Based Assessment. The desired outcome was to find strategies that would support students into passing AP Physics exams, which may translate into college and career readiness in physics. Whether or not these assessment strategies helped student learning, the results from this study will be used to shape instruction and planning in the future.

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).

Treatment

The treatment in this research consists of two assessments that utilize two different strategies using assessment *for* learning, and a non-treatment where nothing additional is included. The two treatments were conducted in two separate learning units on (1) circular motion and gravitation, and (2) energy; the non-treatment was tested in a third unit, on (3) momentum. All three units continued with a classroom routine and as much consistency as possible amongst the varying units. Students completed the test at the beginning and end of each of these three units. The pre- and posttests are summative and were exact copies in order to measure student outcomes. The tests provide comparable data in order to draw conclusions about the efficacy of the two assessment strategies that were implemented, as compared to the baseline where no assessment strategy was used.

For each unit used in this research, students completed the pretest before diving into any content. All tests were generated under Quizzes in AP Classroom and included the first 20 multiple-choice questions that did not repeat. Instead of reading and selecting test questions, I simply selected the first 20 to eliminate bias from the process (Appendix B). All questions included on the exams are included in Appendix B, except those that College Board deemed restricted access and cannot be shared outside of AP classroom (2022). Of the 60 questions for the three pre- and posttests, there are 18 test questions that may be published in this research (College Board, 2022).

Circular Motion and Gravitation Unit

The first unit tested, unit three on circular motion and gravitation, served as the baseline for the study. Students build on their prior knowledge of kinematics for this unit by adding the circular component to motion. There were no changes to regular classroom protocols or activities. Students learned about circular motion and gravitation both (a) conceptually with simulations and video as well as (b) mathematically with labs and practice problems. Anchoring phenomena in this unit examined riding elevators, the *gravitron* ride at the fair, and the explanation of feeling weightlessness, as in space. Examples of test questions that may be published from this unit in Appendices B through D.

Energy Unit

The second unit tested in this study, on energy, involved the assessment strategy identified as Documented Problem Solutions (Appendices E through F). Throughout the unit, students completed homework assignments in which they solved physics problems then wrote out or audio recorded the steps taken to solve the problem. Throughout the unit, students learned about mechanical energy and built marble roller coasters. Anchoring phenomena included the pendulum, the metaphor of energy as a toolbox with a variety of tools inside, and gravitational potential energy compared to a potential energy due to a point source charge.

Momentum Unit

The third unit tested in this study, on momentum, Performance-Based Assessment that utilized NGSS SEPs (Appendices G - K). The first two assessments asked students to use mathematics and computational thinking. One assessed students' ability to design an investigation. The last Performance-Based Assessment used included (a) using mathematics and computational thinking, (b) design and investigation, (c) analyzing and interpreting data, and (d) the Crosscutting Concept regarding energy. The momentum anchoring phenomena included car crashes, colliding clay, rubber bands, and center of mass demonstrations.

Data Collection and Analysis Strategies

In this study, three data collection instruments were used to collect qualitative and quantitative data: (1) Pretest and Posttest for Units 3 through 5, (2) Likert-Scale Survey with Open Interview, and (3) NGSS Comparison. Each instrument allowed for the collection of data in alignment with and to answer the research question for this study (Table 1).

Data Triangulation Matrix

Table 1. Data Triangulation Matrix, (*N*=21).

Data Collection Instruments	Does *documented problem solutions,* a classroom assessment technique, improve students' test scores on AP summative exams?	Do *performance-based assessments*, using NGSS science and engineering practices, improve students' test scores on AP summative exams?
Pretest in AP Classroom 20 multiple-choice questions	X	X
Posttest in AP Classroom copy of 20 multiple-choice questions	X	X
Likert-Scale Survey	X	X
Written Comments and three Open-Ended Questions	X	X
NGSS Comparison: Which of the 3-dimensions of NGSS are present in the pre- posttests, and how frequent?	X	X

Data Collection Methods

Pretest posttest. The pretest and posttest data collection is the baseline and assessment of learning utilized in this research. The pretest is the baseline of students' understanding and the posttest provides comparable data to analyze student achievement with regards to the treatment between the two tests. For each unit during the treatment and non-treatment phases, the pretests and the posttests, were identical to each other, resulting in three different pretest posttest cycles. Each test is created in the appropriate unit of College Board's AP Classroom website. The test included 20 multiple-choice questions. The questions varied in content and in the skill tested. Questions included science practices, content knowledge, and problem-solving skills. For this study, I chose the first 16 multiple choice questions, ensuring there were no repeats. The exam was administered online during class. Results were immediately provided to the students and the researcher. Figure 1 illustrates the action research, where assessment strategies are tested and measured with pre- posttests for comparison.

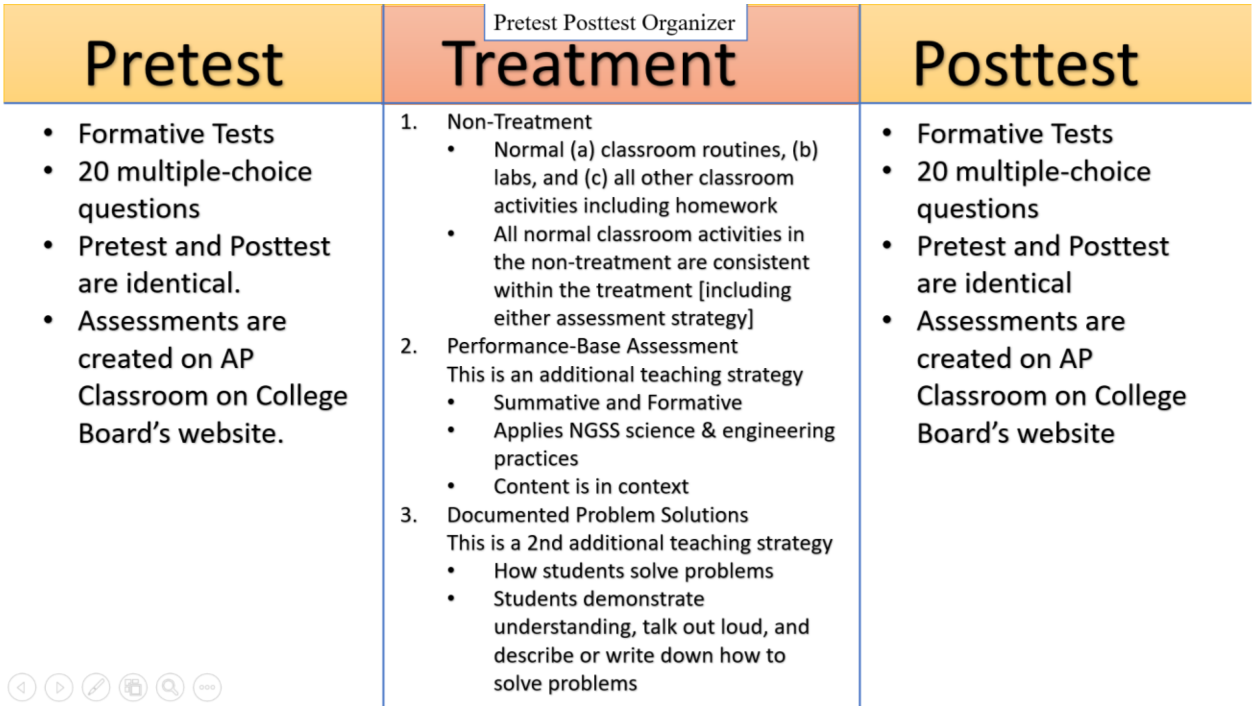

Figure 1. Pretest/posttest outline, (*N*=21).

Measurement of student achievement was collected from the matching pretest and posttest. This quantitative data was collected three times in order to compare scores and see if one of the treatments improved student scores. This data was graphed, using stacked bar graphs and whisker box plots, and shared with students to interpret and analyze.

<u>Likert Scale Survey.</u> To validate conclusions based on the pretests and posttests, more information was gathered in the form of qualitative data. Students completed a Likert survey (Appendix D) summarizing whether or not the treatment strategies proved helpful in achieving the learning objectives. There were a variety of questions on the survey and the response options included (a) strongly agree, (b) agree, (c) neutral, (d) disagree, and (e) strongly disagree. Along with the Likert scale responses, open-ended questions and room for comments were incorporated in this survey for students to give additional comments. This provides the students with the space

to explain their reasoning for their Likert scale responses and provided more insight into the range and distribution of the data collected during the pretests and posttests.

NGSS Comparison. In addition to these two data collection methods, each 20-question test was compared to the Next Generation Science Standards (NGSS) which encompasses 3-dimensions (1) disciplinary core ideas, (2) science and engineering practices, and (3) crosscutting concepts. The comparison of each test to a checklist of the 3-dimensions was made to identify and quantify how closely aligned the test questions were to these standards. Using this method as a checklist, Appendix J, each test utilized in this research was represented by how many standards in the 3-dimensions of NGSS were present in each of the 20 test questions. The purpose of this data collection method was to compare the pretests posttests with the 3-dimensional standards of NGSS. Figure 2 shows an illustration of the data triangulation of the three data collection methods.

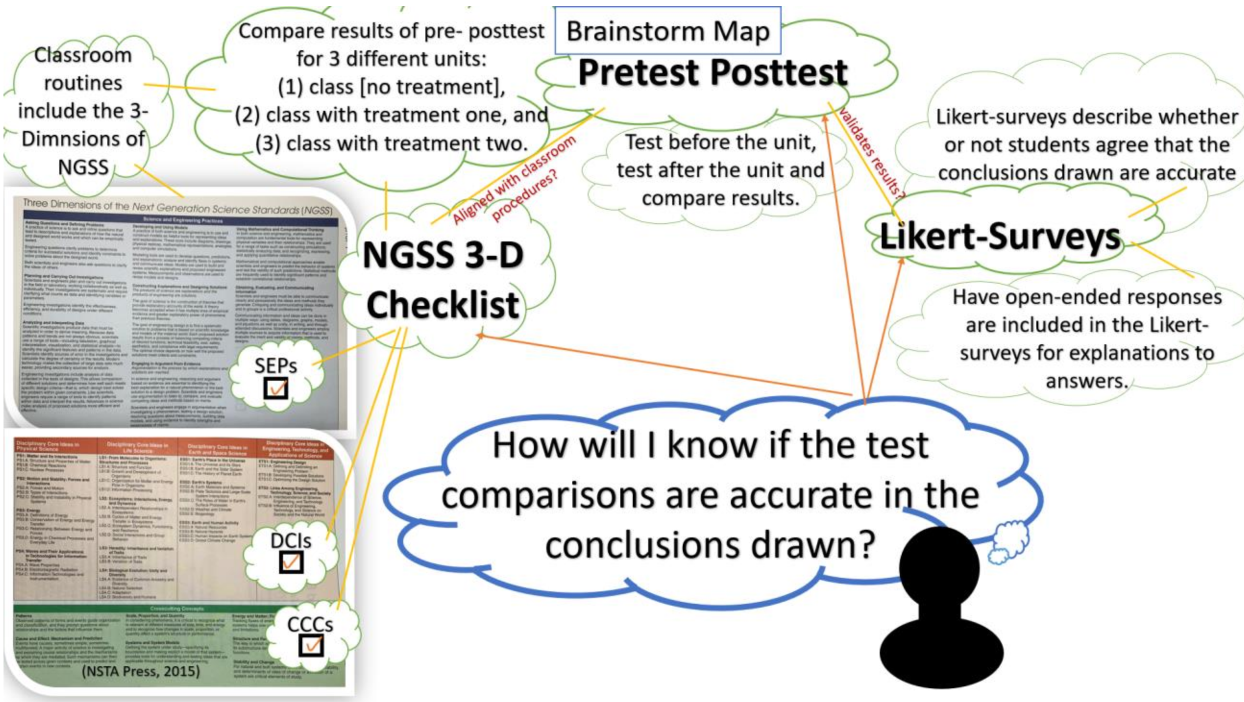

Figure 2. Data triangulation of data collection strategies.

<u>Analysis Strategies</u>

<u>Pretest and Posttest.</u> Stacked bar graphs visualized students' overall achievement on the pretests and posttests. Bar graphs were used because they show the averages and distribution of raw data (Bowen & Bartley, 2014), and because one of the features on the College Board's website is to immediately display student scores with color-coordinated stacked bar graphs. These scores were colored in green and yellow to demonstrate student progress. Scores 75% or better are dark green, 50-74% are light green, 25-49% are light yellow and below 25% are dark yellow. This allows the students and the teacher to gauge student success as a whole but does not accurately describe individual success in detail.

Bar graphs show more detail when the raw data is included as well. Bar graphs easily compare means, in this case between the pre- and posttest. The average is at the top of each bar. The raw data is also included to consider range and distribution patterns. According to Bowen &

Bartley (2014), scientists draw conclusions by analyzing the averages and the distribution of the raw data. Therefore, whenever possible, all data points are included as well the averages. In this way, the data is visual by including the range of data, dispersion patterns, and overlap. For example, the ANOVA is applied to compare two tests from different treatments to support whether or not there is a statistical difference without bias (Bowen & Bartley, 2014). The ANOVA test analyzes how much data overlaps in relation to all the raw data which is why the overlap will be well considered in this research (Bowen & Bartley, 2014). Examining the overlap provides insight on percentage certainty. In order to see the range distribution in comparison to the median and mean of student scores, another graphing method is used.

The whisker and box plot is used to compare of the means and distribution of the class data. This graph easily identifies the median and the variability of the data (Frey, 2018). With 50% of the data in the central box and the remaining 25% above and below as the whiskers, this visual allows the research to easily identify outliers and any skewness of the distribution (Frey, 2018). For example, data skewed to the right shows a long *tail* trailing to the right (Frey, 2018). Therefore, the researcher analyzes the length of the whiskers as well as the size and location of the boxes in the whisker and box plot graphs. This graph along with all bar graphs should paint a quantitative picture in order to draw conclusions.

Likert Survey. Another piece of the puzzle is the analysis of qualitative data. The qualitative data collected in this research was collected using Likert surveys. Likert surveys allow the researcher to add numerical value onto qualitative data (Frey, 2018). The data was graphed with bar graphs to sum and compare student responses. The frequencies of student responses were visible. On the student surveys with the Likert-scale questions, there was additional space for open-ended comments. Additional comments were categorized and themes were presented. This qualitative data helped put the quantitative data in context, in order to draw conclusions about the pretest, treatment, then posttest results.

NGSS Comparison. NGSS is the current model of what learning looks like in the classroom, which encompasses 3-dimensions (1) disciplinary core ideas, (2) science and engineering practices, and (3) crosscutting concepts. These 3-dimensions are guidelines for classroom learning objective in everyday routines in addition to the AP curriculum from College Board. That is why each test was conducted and compared to a checklist of the 3-dimensions in order to quantify how frequently each standard was present, see Appendix K.

This analysis was relevant to the study because the daily classroom procedures, routines, and instructional strategies align to NGSS and College Board's curriculum for Physics 1. Therefore, a comparison of how relevant NGSS is in the tests provided insight into how certain the results of this study were. Using this method, each test utilized in this research can be represented by how many standards in the 3-dimensions of NGSS (Appendix M) are present in each of the 20 test questions.

CHAPTER FOUR

DATA ANALYSIS

Results

The timeline for the classroom implementation in this study was within a 3 month window of time. Unit three in this study was, the non-treatment, where regular class procedures resumed in order to collect a baseline measurement of student outcomes in the circular motion and gravitation unit. Unit four focused on mechanical energy and utilized the CAT called Documented Problem Solutions (Angelo et al., 1993). Unit five included momentum which is where students completed multiple Performance-Based Assessments. The purpose of this study was to test whether or not either of these two assessment strategies improved students' learning of physics content and practices.

Assessment Results from Documented Problem Solutions and Performance-Based Assessments

The treatments, Documented Problem Solutions and Performance-Based Assessments, implemented during units four and five were ineffective at helping students succeed in passing an AP Physics practice test. Prior to the treatments, baseline pretest and posttest assessments were implemented in Unit three. Two students earned passing scores of 50% correct or better on the pretest and nine students earned passing scores on the posttest (N=21). In Unit four, the treatment of Documented Problem Solutions was implemented. For this treatment, one student earned a passing score on the pretest and five students earned passing scores on the posttest (n=21). Lastly, in Unit five, where the treatment Performance-Based Assessment was implemented, no students earned a passing score on the pretest and one student earned a passing score on the posttest (*n*=21). Furthermore, no student scored above 50%, meaning no student passed the AP level exam, which is worse than the pretest for unit 3 which had no treatment. This suggests that neither of these treatments were effective in helping students succeed in passing an AP Physics practice test (Figure 3).

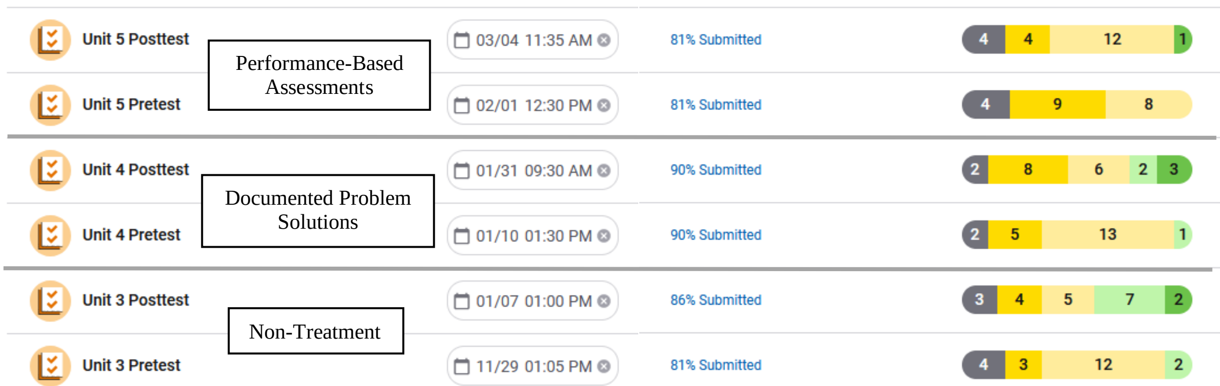

Figure 3. Data on AP Classroom provided by College Board (2020), (*N*=21).

In Figure 3, the stacked bar graphs are color coordinated with (a) dark green for students scoring 75% and above, (b) light green for scores between 50% and 74.99%, (c) darker orange for scores between 0-24.99%, (d) light orange for scores between 25-49.99%, and (e) dark grey color indicates students who did not complete the test (College Board, 2022).

The pretest and posttest displayed as a whisker-box-plot graphs shows the mean increased the most in Unit 3 followed by Unit 5 (Figure 4). This suggests that neither of these treatments proved effective in helping students succeed in passing an AP Physics practice test.

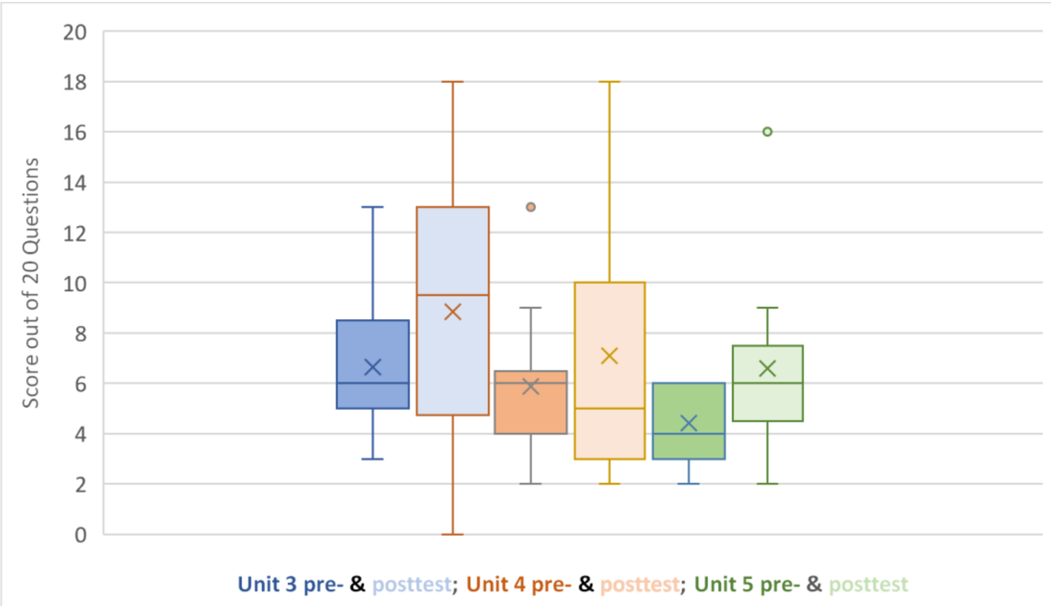

Figure 4. Whisker-box plots of the test results from this study, (*N*=21).

The range of the data also supports that these treatments as ineffective towards student outcomes. Figure 4 shows the posttest score for Unit 3 had higher scores for the top 25% of students' scores, shown in the whiskers, and the top 50% of students' scores shown in the upper quartile. The pretest mean and range steadily decresed over time starting with Unit 3 (Figure 4). The posttest data means and ranges also decrease over time starting with Unit 3 and the range of the all posttest scores are spread wider than all pretest comparisons.

Aggregate and Individual Student Non-Treatment Results. In Unit 3, the baseline results show passing scores doubled. Less than 25% of students passed the pretest where almost 50% passed the posttest. The median increased by 15% and the mean increased 10% without overlap showing an increase in scores did occur (Figure 4). On the pretest, 10% of students earned passing scores, and almost 50% earned passing scores on the posttest (Figure 4). The scores for the pretest ranged from three to 13, which is 10-point range of data distribution, where the range for the posttest was zero to 18 which is an 18-point difference. The entire pretest box overlaps the bottom half of the posttest data and shows no overlap above the median of the posttest data indicating improvement (Figure 4).

It would be beneficial to look at students' individual scores for this unit in order to further examine whether or not there is a significant increase in the outcome, see Figures 11-13. Figure 5 shows individualized results for Unit 3 results where there was no treatment. Figure 5 illustrates how three students doubled or almost doubled their scores, three students improved by three or more points, three students improved by one or two points, one student score stayed the same, and two students scored lower on the posttest when compared to the pretest results.

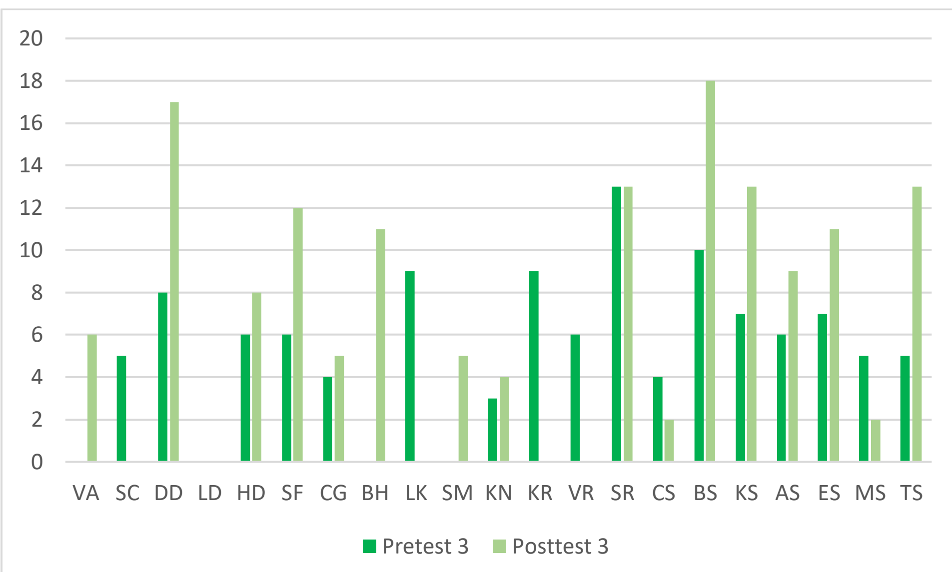

Figure 5. Individual scores for the pretest and posttest in Unit 3, (*N*=21).

<u>Aggregate and Student Individual Documented Problem Solutions Results.</u>In Unit 4, only one student passed the pretest which is an extreme outlier, and 25% of students passed the posttest (Figure 4). The median decreased at least one point which signifies that a handful of

students scored worse on the posttest (Figure 4). The mean increased but by about one point so there is slight overlap. Only one student, who accounts for 5% and is also an outlier, earned a passing score on the pretest and 25% of students earned a passing score on the posttest (Figure 4). The lowest score is the same for the pre- and posttest. The highest score on the posttest increased nine points from the upper quartile and five points when compared to the high scoring outlier on the pretest (Figure 4). The range of data distribution on the Unit 4 pretest is only seven and 16 points on the posttest, which is a nine-point difference (Figure 4). The pretest data shows much overlap. When ignoring the outlier, the entire upper quartile and upper part of the box overlaps the upper part of the posttest box indicating improvement only in the upper quartile during the posttest in Unit 4. Figure 6 demonstrates Unit 4, with Documented Problem Solutions as the treatment, where three students scored worse on the posttest, six students doubled their scores on the posttest, two students scored slightly better and two students earned the same score. This individualized student score bar chart illustrates more detail.

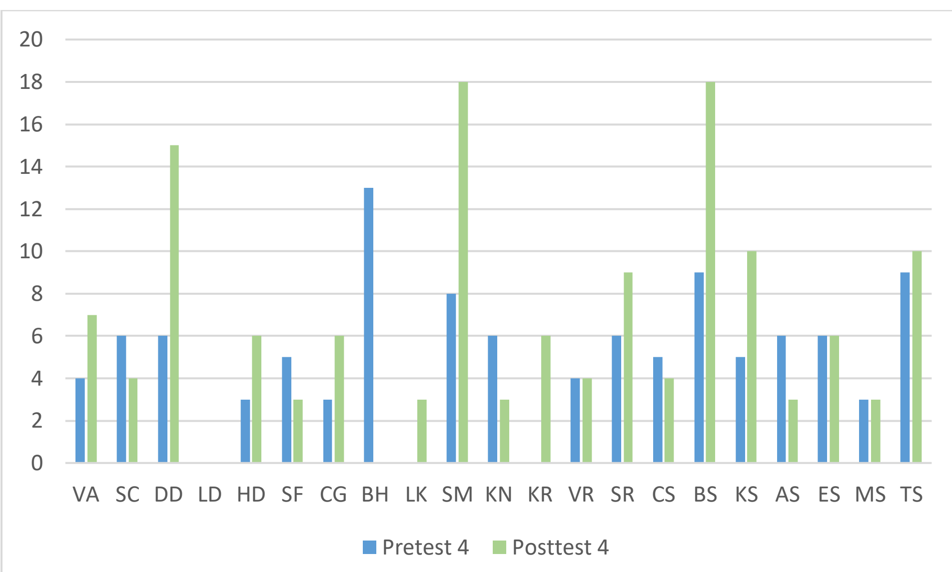

Figure 6. Individual scores for the pretest and posttest in Unit 4, (*N*=21).

Aggregate and Individual Performance-Based Assessment Results.In Unit 5, no student passed the pretest and the average score is 25% in addition to half of the students' score were less than 25% (Figure 4). Only one student passed the Unit 5 posttest, which is an extreme outlier, and all other scores did not pass. The median increased by two points and the mean increased also by about two points (Figure 4). No students earned passing scores on the pretest and only one student, less than 1% and is an outlier, earned a passing score on the posttest (Figure 4). The lowest score on the pre- and posttest are the same. The highest score on the pretest in unit 5 is also the extent of the upper quartile looking like student scores hit a wall. The highest score on the 5 posttest is an outlier earning the top percentile, otherwise the upper quartile is below passing (Figure 4). The range of data distribution is within four points on the pretest and within seven points on the posttest, only a three-point difference. The upper half of the box and the entire upper quartile overlaps the bottom half of the box in the posttest data indicating for at least half of the students (Figure 4). This data shows an increase in the mean while also showing no students with passing scores.

Individualizing student scores may provide more visualization on student outcomes for the unit that utilized Performance-Based Assessment, see Figure 7. When the students' individual pretest scores are next to the posttest scores, the first thing that stands out are that two students scored worse on the posttest. A factor that would skew the data, shown in Figure 7, is where one student completed the pretest and not the posttest then another student completed the posttest but not the pretest. The second factor that stands out in Figure 7, is how one student scored the same score then all the other students scored better on the posttest in comparison to the pretest. 12 out of the 15 students who completed both tests scored higher and half of those students scored significantly higher than they did on the pretest. These individual student scores certainly provide more insight and is worth comparing to the other tests in this format, see Figure 6 and 7. The next step is to analyze student feedback.

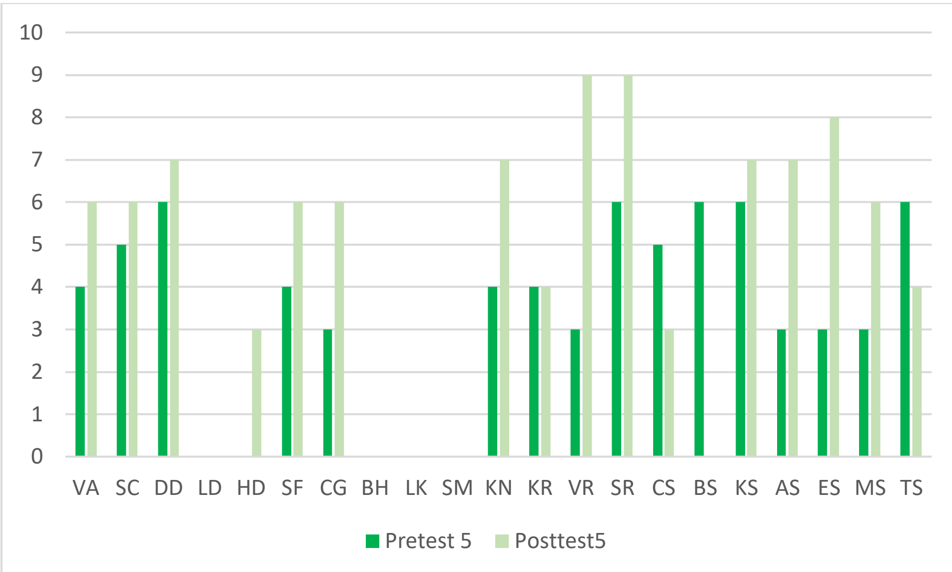

Figure 7. Individual scores for the pretest and posttest in Unit 5, (*N*=21).

Student feedback.To validate these results, student feedback is critical. Figure 8 quantifies student responses from the Likert scale survey. According to the bar graphs showing the Likert-scale data in Figure 8, Documented Problem Solutions was the most agreeable treatment from the student perspective and students found practice problems, labs and simulations also helpful in learning and retaining physics content.

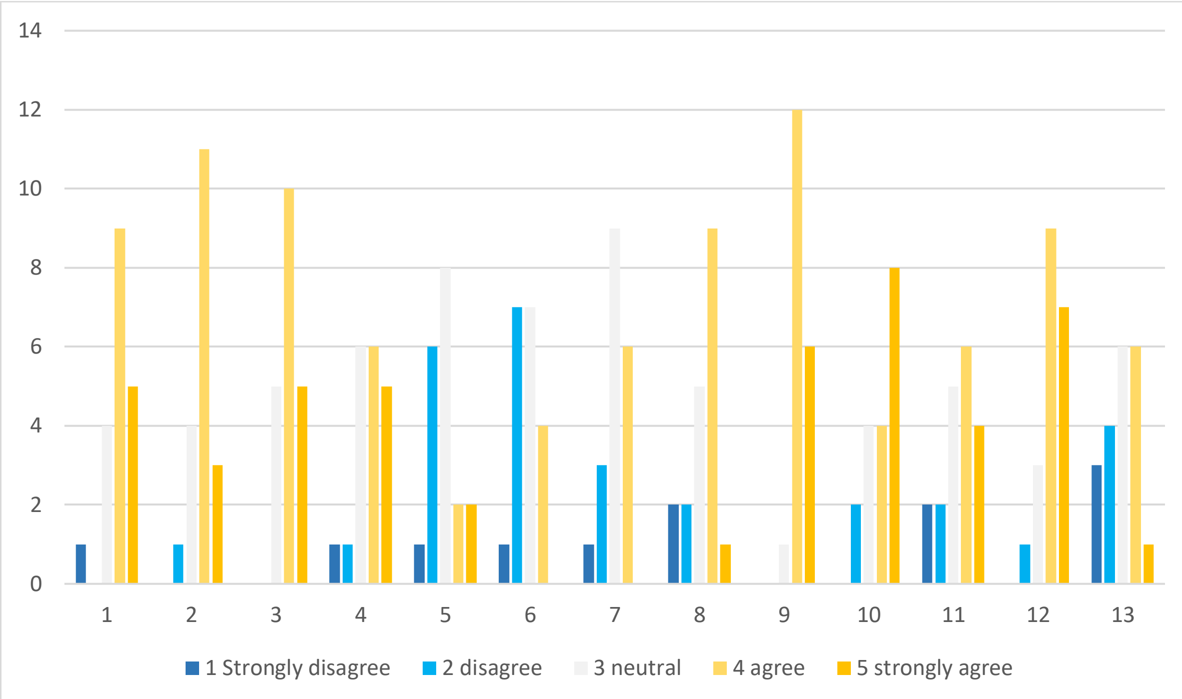

Figure 8. Likert-scale data from a student survey regarding this research, (*N*=21).

The Likert-scale results show students are in favor of the Documented Problem Solutions method. Questions one through four asked students if the process of Documented Problem Solutions were helpful in various ways. The first three questions show at least 70% agreement, and more than 50% in agreement with question four. 60% of students agree that physics labs are helpful to learn physics. And 50% agree that online simulations are helpful to learn physics.

According to the Likert-scale results, students did not find value in the Performance-Based Assessments as a tool for learning physics. Questions five through eight ask students if they found Performance-Based Assessments useful or helpful in a variety of manners. Questions five through eight have the highest neutrality in student responses. Questions five at 35% and question six at 40% have the highest disagreement in comparison to the other questions. There is the same amount of disagreement on questions seven and eight which is 20%. Question eight noticeably shifts towards more agreement at 50%. Yet most notably, the neutral answer is chosen more on questions five through seven than anywhere else on the survey.

Questions nine through 13 are general questions and show students unanimously value practice with physics problems and mostly support laboratory experiences and simulations. Question nine asks if practicing physics problems is helpful to learn physics and student agreement is at 90% and 5% neutrality. Figure 6, has the same data from the Likert survey but as a stacked bar graph in order to compare students who agree and disagree as a whole. Question 12 asks students to rate how actively they participate in their own learning in this physics class. 85% of the students in this physics class identify has hardworking and very hardworking at participating as a student in this classroom. 35% of these students agree that the AP Classroom pre- and posttests used in this study were reasonable and 35% disagreed.

<u>NGSS comparison</u>.In this study all test questions were reviewed and compared to the 3-dimensions of the Next Generation Science Standards [NGSS] (Figure 9). This AP Physics classroom engaged in NGSS for what to learn, as well as a way of learning. The three dimensions of NGSS included (1) science and engineering practices, (2) disciplinary core ideas, and (3) cross-cutting concepts. After the data was collected, I completed each pre- and posttest and then tally marked which practices, ideas, and concepts were utilized in the process of answering the question correctly. The tests included the SEP using mathematics and computational thinking for all questions (Figure 9). The DCI's included were forces and motion as well as types of interactions (Figure 9). And finally, the CCC's included concepts around energy (Figure 9). It is appropriate that computational thinking is present in every physics test question utilized in this research. The data anomaly shown in Figure 9, is that the only SEP present is using mathematics and computational thinking. Recall these tests are multiple-choice

tests, there would be a variety of science and engineering practices on free-response questions which were not utilized in this study. Next, there are only four DCI's, meaning disciplinary core ideas, present in these tests. And absolutely no CCC's or cross-cutting concepts. Next, the disciplinary core ideas represented here is isolated in Figure 9.

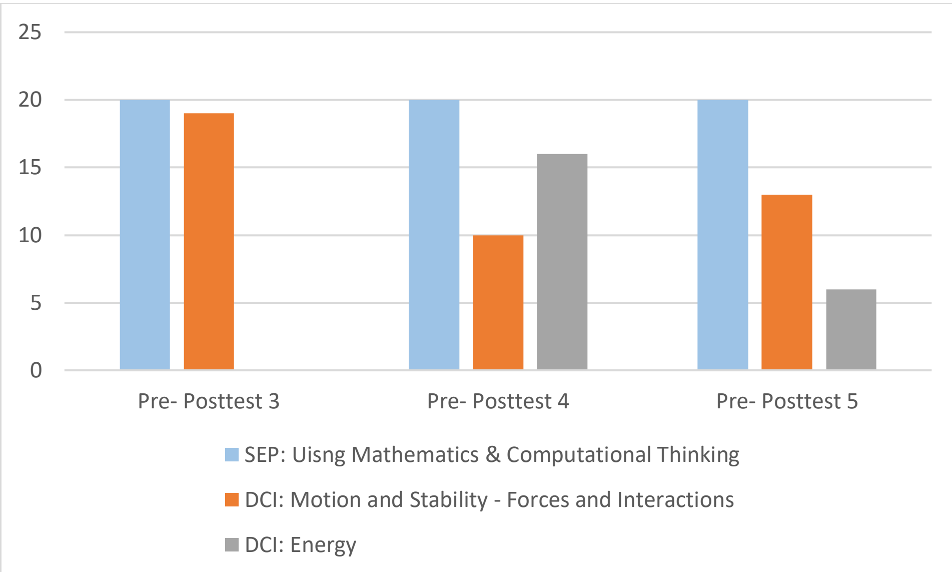

Figure 9. NGSS comparison demonstrating the frequency of relevance to each question.

Figure 9 emphasizes that every question on every test included some format of using mathematics and computational thinking. All tests had at least 50% of questions relating to motion and stability – forces and interactions. The unit 3 pre- posttest had no question relating to energy. The unit 4 pre- posttest included energy in 80% of the questions, meaning not all the questions on that test related to energy, which were questions referring to kinematics and dynamics rather than work or mechanical energy.

<u>General Student Feedback.</u>Students were asked three open-ended questions including:

1. Overall, I am more confident in my understanding of physics content because…,
2. Overall, I am more confident in my explanations of physics content because…
3. I learned physics content best by a method not mentioned in this survey, and that is…

Student responses were then compiled into the word cloud (Figure 10).

Figure 10. Student responses from all three open-ended questions combined.

There were five words that appeared most often in the word cloud: (a) Labs, (b) Practice problems, (c) Group work, (d) Notes, and (e) Understand. The largest word in the word cloud was Labs, meaning that students responded with "labs" on each of the three answers to the three open-ended questions and the size of the word in the word cloud reflects that. The second largest word was Practice problems, followed by Group work, Notes, and Understand. For example, a

20% of student responses included a phrase similar to “I understand physics now” even though this phrase was not what the survey questions were asking about. Notes was highlighted next in order, followed by equations, explanations and videos. There are many more student responses where one person out of the class mentioned things like simulation, discussions, repetition, and models.

CHAPTER FIVE

CLAIM, EVIDENCE, AND REASONING

Claims From the Study

Value of this Study for my Classroom

I began this action research wondering whether or not specific assessments for learning were effective in helping physics students learn and succeed on summative assessments. I learned there is potential for student success with Documented Problem Solutions and Performance-Based Assessments. These strategies need to be revised and refined for future planning and implementation from the teacher perspective, and these strategies should be tested in various units to clearly measure student outcomes and success.

Value of Researching Documented Problem Solutions

I conclude that Documented Problem Solutions is a strategy with potential to support student learning for using mathematics and computational thinking. There is some evidence quantitatively and qualitatively that doing physics problems then discussing and/or writing each step out, is an effective approach in an AP Physics classroom. A majority of students found Documented Problem Solutions facilitated confidence in solving physics problems and in better understand physics content. The overall average test scores did increase after utilizing this strategy, but the range of data also increased resulting in more students earning lower scores after utilizing Documented Problem Solutions. In order to better understand why this happened, inconsistencies in the classroom and in the test taking must be defined.

First, who accounts for the 10% of students who did not complete the pretest and the posttest? When I look at the names in Figures 5 through 7, I find that one male student consistently did not take all pre- and posttests. The pretest in Unit 4, where Documented Problem Solutions is tested, one male student did not take the pretest but did take the posttest, and one female student did take the pretest but did not take the posttest. This female scored high, the light green color which is a passing grade at 65%, on the pretest. The male who took the pretest scored a 25% which is close to the median and mean when compared to the class data. These inconsistencies do not contribute to the overall drop in the class median on the posttest data. Therefore, there are a couple of students who did worse on the posttest by one or two questions. When referring to Figure 6, there were two students who did worse on the posttest compared to the pretest in Unit 4. At the same time, the Likert scale survey shows only one student disagreeing with the usefulness of documented problem solutions, see Figure 8. Students also somewhat agree that Documented Problem Solutions helped them recall physics content. Again, the tests utilized in the research focused on using mathematics and computational thinking, emphasized in Figures 15 and 16. If these tests simultaneously reflected other NGSS science and engineering practices, like the AP Classroom free-response questions do, would students feel the same about this assessment strategy? That is a good question for another action research. But there is evidence suggesting that Documented Problem Solutions may be an appropriate assessment strategy for learning physics in a high school classroom.

Value of Researching Performance-Based Assessments

The next question is whether or not Performance-Based Assessments, that utilize various SEPs, is an effective tool for student learning in physics. The answer to this question seems like a straightforward “maybe”. Refer to Figures 4 where the mean does increase and recall that in, Figure 7, 80% of individual student scores improved. The box plot shows a clear increase in the top half of the class on the posttest with no overlap to the pretest, but no student earned a passing test score. When examining Performance-Based Assessments qualitatively, students were noticeably neutral in their Likert-scale survey responses. Interestingly, more students disagree than agree with the effectiveness of performance-based assessment for learning physics. In addition, the open spaces for student comments, on this Likert survey, frequently included phrases like *I'm a bad test-taker,* and *I don't like tests.* These student responses where general and not specific to the type of testing that was seen as unfavorable, but many students commented about testing. On the other hand, I enjoyed grading the Performance-Based Assessments because it allowed the teacher to see a broad range of evidence for student learning, rather than multiple-choice questions or physics problems. For example, students were analyzing and interpreting data, constructing explanations, and demonstrating critical thinking skills in these Performance-Based Assessments. The complexity of these assessments also means they are challenging. It may be possible that students did not like how these tests were not quick and easy. One last main point is the is an elephant in the room called momentum. When you step outside the box of these test results, you see a unit on momentum being compared to energy and circular motion.

Identifying Inconsistencies in the Units Used in this Study

Students often have prior experience and background knowledge with energy and the law of conservation of energy. Most students have likely had classroom experiences regarding energy like with food chains, chemical reactions, Earth systems, and the electricity in their daily lives. There are no elementary or middle school units dealing with momentum. The law of conservation of momentum is equally important as the law of conservation of energy, but the difference is that momentum is a new concept which makes it more difficult to learn. Learning occurs when students grapple with new information and fit it within their mental schematic of the material based on prior knowledge of the thing being learned (Windschitl et al., 2018), Most students hear impulse and p = mv for the first time in their first physics class. Therefore, there is not the prior knowledge for these students to build on, as there is with respect to energy. And circular motion is building on prior knowledge from learning kinematics and dynamics at the beginning of the school year. In conclusion, it is difficult to compare the units and their results. It is like comparing apples to oranges, and knowing that does shed a different light on the results. Since there is pretest and posttest data for each unit, the results are still worth evaluating.

In the non-treatment, unit three, there is strong evidence of student improvement on the posttest when compared to the pretest. In this unit, there is no overlap in the upper quadrant or quartile of the whisker box plot. This suggests that whatever went on in the classroom daily routines was helpful for students learning physics. The question is what did occur in this classroom? And if this is the baseline, should student posttest scores show even more improvement for the assessment strategies that may have been effective? The obvious answer is yes, of course for a classroom that is consistent where the only variable changing is the strategy tested in this action research. The results should demonstrate a much higher degree of certainty in support of effective assessment strategies. But since there is overlap in the data and since the scores do not encompass the non-treatment baseline, the classroom routines are clearly not consistent.

Identifying Inconsistencies in my Classroom

The timing of this action research and what I teach is not conducive to routine and consistency. This is my sixth-year teaching and I started teaching Biology. I no longer teach Biology and this is only my second-year teaching AP Physics, yet only my first-year as an in-person instructor. Therefore, even though I strive for routine and procedures that work; as a new physics teacher, I still continue to try new strategies in order to find what work best. The Likert-scale data does suggest that most students view the in-person laboratory work and online simulations, which were utilized in all three units, were helpful in learning physics. And this action research did shed light on two specific assessment strategies for learning, but more practice at implementation and refining such strategies is needed.

Value of the Study and Consideration for Future Research

I believe there is potential for both strategies tested in this action research. Documented Problem Solutions did show improvement and students' responses were positive and encouraging. When it comes to using mathematics and computational thinking, Documented Problem Solutions is a strategy that is relevant and appropriate. Most students state that they actively participate in their learning, which supports the validity of this qualitative data. Students also highly support practice problems in physics. This seems like a no brainer since the multiple-choice questions all related to using mathematics or computational thinking. With more practice at implementation in addition to purposefully organizing the sequence of instructional and classroom activities, the documenting problem solutions assessment strategy has potential to support student success in AP Physics and on the AP exam.

On the other hand, Performance-Based Assessment that make use of the NGSS science and engineering practices, may be better tested with College Board's free-response questions rather than the multiple-choice questions. This is certainly an action research worth furthering in the future. There is some evidence that Performance-Based Assessments were successful and worth spending more time revising, refining, and retesting.

Impact of Action Research on the Author

First of all, it seems Documented Problem Solutions has potential. This will continue to be a strategy I use in my AP Physics classroom and that I will refine with more practice. For example, I found giving this assignment to students while there is still time in class is a successful strategy because it provides students with time and space to discuss how they are solving physics problems. I liked seeing that and the students liked discussing physics in small groups. The next time I teach kinematics, I will use documented problem solutions for simple derivations in addition to physics problems. I would like to see if this process of writing down the steps and talking about it out loud, helps students recall the information in the future.

What I realize now, is that sequence matters. I recall one day when a student brightened up. She was excited that she knew how to solve a multi-step physics problem on the homework by applying what she learned the previous day. The answer required the student to include prior knowledge and apply what was learned to a different scenario with increased complexity. The reason for this student's success was due to the sequence of lessons and activities in the classroom. She applied multiple concepts in a two-step problem that we built one at a time. This student example was from unit three, during the non-treatment, and I feel unit four and five were more scattered in terms of the learning sequence.

Another point I see now, is how we track our progress in learning the science content. In my other science sections, I feel learning is most evident with initial and final models where students may reference summary charts tracking what we learn. In my physics classroom, tracking our learning is scattered and not clearly tracked. This has inspired me to keep my own notebook, tracking lessons, equations and notes. This documentation will help me find the right sequence of events for learning and allow me to plan backwards in the coming years so the learning objectives, and steps to get there, are clear.

Now to answer the question about what impact this had on how I utilize and implement the assessment strategies tested in this action research. I would like to say the Performance-Based Assessments were not a hit because it was challenging. Research supports the fact that Performance-Based Assessments are effective (Smith, 2007). I liked seeing what students wrote, in the Performance-Based Assessments, because it showed me if they understood the content in context. I think results in this study reflect that this was my first time really trying it out in the classroom. I think I could revise and refine (a) how to use it, (b) when to use it and (c) what content or processes are included in the Performance-Based Assessments. In future planning I think it would be beneficial to implement this strategy in other units. And what I learned in this research, is the importance of ensuring the questions are grade-appropriate and layered in complexity to see how deep students' knowledge is rather than having questions with right or wrong answers. And in order to ensure it is an effective strategy, I will utilize the free-response test questions in AP Classroom on College Board's website to do further action research on this topic.

Student explanations provide the clearest picture when analyzing student work. What is clear from student feedback is that these students like group collaboration and talking out loud when solving physics problems. I learned allowing class time for homework completion is valued by my students.

I did learn that AP Classroom, by College Board, is a great resource to easily practice action research with the pretest posttest format. Assigning tests and making copies of those tests are easy and the data is instantaneous for students and for the teacher. When I do this in the future, my next step is to use the AP Classroom resource to create performance-based assessments in a variety of units that work towards supporting and motivating student learning.

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APPENDICES

APPENDIX A

IRB Exemption

Appendix A: IRB Exemption

Exemption Regarding Informed Consent and Administrator Approval

I, David Monson, Principal of Nordhoff High School, verify that the classroom research conducted by Annelisa Cohen is in accordance with established or commonly accepted educational settings involving normal educational practices. To maintain the established culture of our school and not cause disrupt to our school climate, I have granted an exemption to ANNELISA COHEN regarding informed consent and I approve this project.

David Monson (Signed Name)

David Monson (Printed Name)

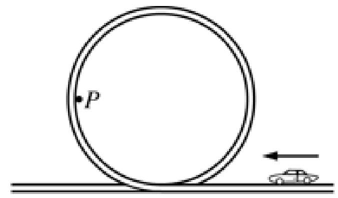
11/15/21 (Date)

APPENDIX B

UNIT 3 PRE- POSTTEST FROM COLLEGE BOARD'S AP CLASSROOM

Appendix B: Unit 3 Pre- Posttest from College Board's AP Classroom

1). The toy car shown in the adjacent diagram enters the vertical circular loop with an initial velocity and moves completely around the loop without friction. If the car has no means of self-propulsion, which of the following is true of the car's acceleration at the instant it is at point *P* ?



a. It is vertically upward
b. It is in the direction of the velocity.
c. It is directly toward the center of the circle.
d. It has components both downward and toward the center of the circle.
e. It has components both downward and away from the center of the circle.

2). An artificial satellite orbits Earth at a speed of 7800 m/s and a height of 200 km above Earth's surface. The satellite experiences an acceleration due to gravity of

a. 39 m/s^2
b. 9.8 m/s^2
c. less than 9.8 m/s^2 but greater than zero
d. less than 9.8 m/s^2 but greater than zero

3). Not Allowed, Official Practice Exam Question
4). Not Allowed, Topic Question
5). Not Allowed, Topic Question
6). Not Allowed, Topic Question
7). Not Allowed, Topic Question
8). Not Allowed, Topic Question
9). Not Allowed, Official Practice Exam Question
10). Not Allowed, Official Practice Exam Question
11). Not Allowed, Topic Question

12). An object has a weight *W* when it is on the surface of a planet of radius *R*. What will be the gravitational force on the object after it has been moved to a distance of 4*R* from the center of the planet?

a. 16 *W*
b. 4 *W*
c. *W*
d. ¼ *W*

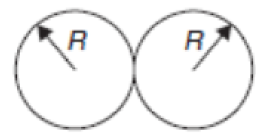
13). Two massive, positively charged particles are initially held a fixed distance apart. When they are moved farther apart, the magnitude of their mutual gravitational force changes by a factor of *n*. Which of the following indicates the factor by which the magnitude of their mutual electrostatic force changes?

a. $1/n^2$
b. 1/n
c. n

d. n^2

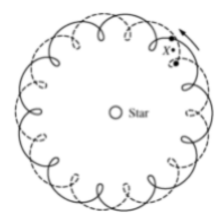
14). Not Allowed, Topic Question
15). Not Allowed, Topic Question
16). Not Allowed, Topic Question
17). Not Allowed, Topic Question

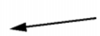
18). Two solid spheres of radius R made of the same type of steel are placed in contact, as shown in the figures above. The magnitude of the gravitational force that they exert on each other is F_1. When two other solid spheres of radius $3R$ made of this steel are placed in contact, what is the magnitude of the gravitational force that they exert on each other?



a. F_1
b. 3V
c. $9F_1$
d. $81F_1$

19). The figure above represents the orbits of two planets of equal mass that orbit their star in the counterclockwise direction as a double-planet system. From the point of view of an observer on either planet, the planets appear to orbit each other while also orbiting the star. The dots on the orbits represent the position of the planets at time t_0, and X is the position of their center of mass at that time. Which of the following arrows best represents the acceleration of the center of mass of the double-planet system when it is at point X ?



a. 
b. 
c. 
d. 

20). Not Allowed, Topic Question

APPENDIX C

UNIT 4 PRE- POSTTEST FROM COLLEGE BOARD’S AP CLASSROOM

1). A rocket is continuously firing its engines as it accelerates away from Earth. For the first kilometer of its ascent, the mass of fuel ejected is small compared to the mass of the rocket. For this distance, which of the following indicates the changes, if any, in the kinetic energy of the rocket, the gravitational potential energy of the Earth-rocket system, and the mechanical energy of the Earth-rocket system?

a.

Rocket Kinetic Energy	**System Gravitational Potential Energy**	**System Mechanical Energy**
Increasing	Increasing	Increasing

b.

Rocket Kinetic Energy	**System Gravitational Potential Energy**	**System Mechanical Energy**
Increasing	Increasing	constant

c.

Rocket Kinetic Energy	**System Gravitational Potential Energy**	**System Mechanical Energy**
Increasing	Decreasing	Decreasing

d.

Rocket Kinetic Energy	**System Gravitational Potential Energy**	**System Mechanical Energy**
Decreasing	Increasing	Constant

2). Not Allowed, Topic Question
3). Not Allowed, Official Practice Exam Question
4). Not Allowed, Topic Question

5). A ball is tossed straight up and later returns to the point from which it was launched. If the ball is subject to air resistance as well as gravity, which of the following statements is correct?

a. The speed at which the ball returns to the point of launch is less than its speed when it was initially launched.
b. The time for the ball to fall is the same as the time for the ball to rise.
c. The force of air resistance is directed down-ward both when the ball is rising and when it is falling.
d. The net work done by air resistance on the ball during its flight is zero.

e. The net work done by gravity on the ball during its flight is greater than zero.

6). Not Allowed, Topic Question
7). Not Allowed, Topic Question
8). Not Allowed, Official Practice Exam Question

9). A person holds a book at rest a few feet above a table. The person then lowers the book at a slow constant speed and places it on the table. Which of the following accurately describes the change in the total mechanical energy of the Earth-book system?

a. The total mechanical energy is unchanged, because there is no change in the book's kinetic energy as it is lowered to the table.
b. The total mechanical energy is unchanged, because no work is done on the Earth-book system while the book is lowered.
c. The total mechanical energy decreases, because the person does positive work on the book by exerting a force that opposes the gravitational force.
d. The total mechanical energy decreases, because the person does negative work on the book by exerting a force on the book in the direction opposite to its displacement.

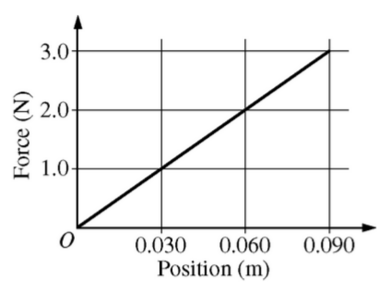
10). Not Allowed, Topic Question
11). Not Allowed, Official Practice Exam Question
12). Not Allowed, Official Practice Exam Question
13). Not Allowed, Official Practice Exam Question

14). Which of the following is constant for an object in uniform circular motion?

a. Kinetic energy
b. Velocity
c. Acceleration
d. Displacement
e. Linear momentum

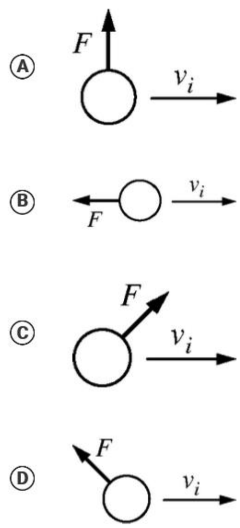
15). Not Allowed, Topic Question
16). Not Allowed, Topic Question
17). Not Allowed, Topic Question

18). The figure above shows the net force exerted on an object as a function of the position of the object. The object starts from rest at position $x = 0$ m and acquires a speed of 3.0 m / s after traveling a distance of 0.090 m. What is the mass of the object?



a. 0.015 kg
b. 0.030 kg
c. 0.045 kg
d. 0.060 kg

19). An object is moving to the right with speed v_i when a force of magnitude F is exerted on it. In which of the following situations is the object's direction of motion changing and kinetic energy decreasing at the instant shown?

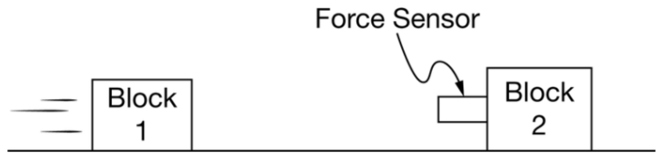


20). Not Allowed, Official Practice Exam Question

APPENDIX D

UNIT 5 PRE- POSTTEST FROM COLLEGE BOARD’S AP CLASSROOM

1). On a straight horizontal track along which blocks can slide with negligible friction, block 1 slides toward block 2, which is initially at rest. Block 1 collides with an electronic force probe attached to block 2, generating a force vs. time graph and causing block 2 to start sliding. What additional measurements must be made to determine the momentum of block 2 after the collision?



a. None
b. The mass of block 2 only
c. The post-collision speed of block 2 only
d. Both the mass and the post-collision speed of block 1

2). Not Allowed, Topic Question
3). Not Allowed, Official Practice Exam Question

4). How does an air mattress protect a stunt person landing on the ground after a stunt?
a. It reduces the kinetic energy loss of the stunt person.
b. It reduces the momentum change of the stunt person.
c. It increases the momentum change of the stunt person.
d. It shortens the stopping time of the stunt person and increases the force applied during the landing.
e. It lengthens the stopping time of the stunt person and reduces the force applied during the landing.

5). Not Allowed, Official Practice Exam Question
6). Not Allowed, Topic Question
7). Not Allowed, Official Practice Exam Question

8). A person applies an impulse of 5.0 kg·m/s to a box in order to set it in motion. If the person is in contact with the box for 0.25 s, what is the average force exerted by the person on the box?
a. 1.25 N
b. 2.00 N
c. 12.5 N
d. 20.0 N
e. 200 N

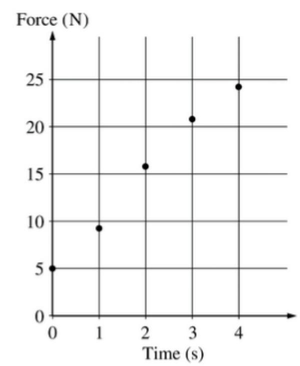
9). A block of mass 2.0 kg, starting from rest, is pushed with a constant force across a horizontal track. The position of the block as a function of time is recorded, and the data are shown in the table. What is the magnitude of the change in momentum of the block between zero and 4.0 seconds?

Position (m)	Time (s)
0.0	0.0
0.1	1.0
0.4	2.0
0.9	3.0
1.6	4.0

a. 0.8 kg·m/s
b. 1.2 kg·m/s
c. 1.6 kg·m/s
d. 3.2 kg·m/s

10). Not Allowed, Topic Question
11). Not Allowed, Official Practice Exam Question
12). Not Allowed, Official Practice Exam Question
13). Not Allowed, Official Practice Exam Question

14). A student obtains data on the magnitude of force applied to an object as a function of time and displays the data on the graph above.



Answer the following question for the information and diagram here. The increase in the momentum of the object between t = 0 s and t = 4 s is most nearly
a. 40 N·s
b. 50 N·s
c. 60 N·s
d. 80 N·s
e. 100 N·s

15). Not Allowed, Topic Question
16). Not Allowed, Topic Question
17). Not Allowed, Topic Question
18). Not Allowed, Topic Question

19). A 2 kg object traveling at 5 m/s on a frictionless horizontal surface collides head-on with and sticks to a 3 kg object initially at rest. Which of the following correctly identifies the change in total kinetic energy and the resulting speed of the objects after the collision?

a.

Kinetic Energy	Speed
Increases	2 m/s

b.

Kinetic Energy	Speed
Increases	3.2 m/s

c.

Kinetic Energy	Speed
Decreases	2 m/s

d.

Kinetic Energy	Speed
Decreases	3.2 m/s

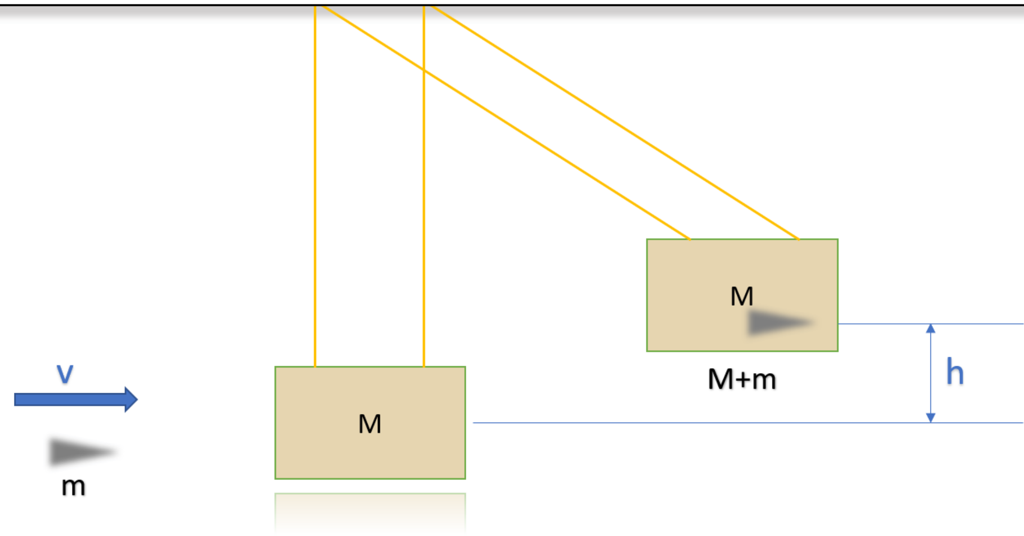
20). Not Allowed, Official Practice Exam Question

APPENDIX E

DOCUMENTED PROBLEM SOLUTIONS: BALLISTIC PENDULUM PROBLEM

Directions: (1) solve the problem below, and (2) explain how you solved that problem, step-by-step, in a paragraph or with a video (Canvas). Submit your work on Canvas.

A diagram of a ballistic pendulum before and after a bullet strikes a wood block that swings.



A ballistic pendulum is a device used to measure the speed of a bullet. A bullet of mass m is fired at a block of wood (mass M) hanging from a string. The bullet embeds itself in the block, and causes the combined block plus bullet system to swing up a height h.

The mass of the block (M) is 870 grams. The mass of the bullet (m) is 30 grams. The height is 0.74 meters.

What is v_o, the speed of the bullet before it hits the block?

APPENDIX F

DOCUMENTED PROBLEM SOLUTIONS:

WORK ENERGY PROBLEM WITH A SLED

Directions: (1) solve the problem below, and (2) explain how you solved that problem, step-by-step, in a paragraph or with a video. Submit your work on Canvas.

Problem 35 on page 163 in the Giancoli textbook (2005)
A sled is initially given a shove up a frictionless 28.0 deg incline. It reaches a maximum vertical height 1.35 m higher than where it started. What was its initial speed?

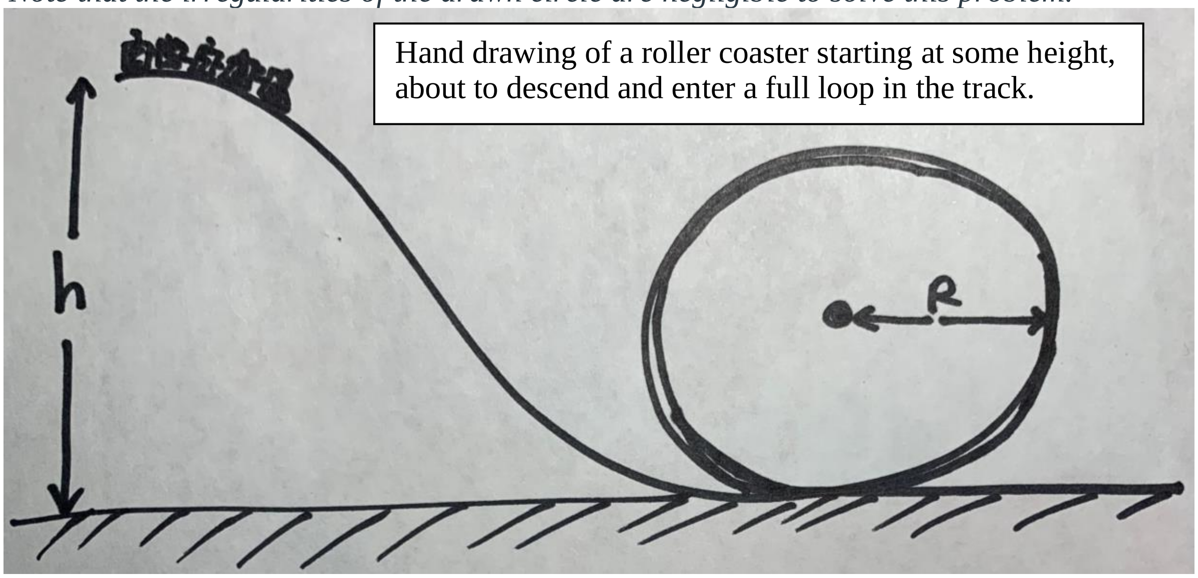
APPENDIX G

DOCUMENTED PROBLEM SOLUTIONS ASSIGNMENT:

WORK ENERGY PROBLEM

Directions: (1) solve the problem below, and (2) explain how you solved that problem, step-by-step, in a paragraph or with a video (Canvas). Submit your work on Canvas.

<u>Problem 82 on page 165 in the Giancoli textbook (2005)</u>
Show that on a roller coaster with a circular vertical loop (diagram below), the difference in your apparent weight at the top of the circular loop and the bottom of the circular loop in 6 g's - that is, six times your weight. Ignore friction. Show also that as long as your speed is above the minimum needed, this answer does not depend on the size of the loop or how fast you go through it. *Note that the irregularities of the drawn circle are negligible to solve this problem.*



Hand drawing of a roller coaster starting at some height, about to descend and enter a full loop in the track.

APPENDIX H

PERFORMANCE-BASED ASSESSMENT:

HEAD-ON COLLISION

Cartoon diagram of a head-on collision between a large truck and a small car.

Use the variables below to calculate the final velocity of the car and the truck after the indicated collisions. Moving from left to right should be considered as positive in direction and moving right to left as negative in direction.

Variable	Car	Truck
Mass (kg)	1,000 kg	3,000 kg
Velocity (m/s)	20 m/s	-20 m/s

1. If the head-on collision between the car and the truck is elastic, calculate the momentum of each vehicle before impact.

2. Describe what happens to each vehicle's motion after impact in the elastic collision.

3. Calculate for a scenario in which the collision is inelastic.

4. Describe what happens to each vehicle's motion after impact in an inelastic collision.

APPENDIX I

PERFORMANCE-BASED ASSESSMENT:

DESIGN AN INVESTIGATION

We learned that momentum equals mass times velocity and that the change of momentum equals the impulse

$$\Delta p = F\Delta t$$

Recall in a perfectly elastic car collision, the initial kinetic energy equals the final kinetic energy.

$$\frac{1}{2}mv^2_i = \frac{1}{2}mv^2_f$$

And we that in perfectly elastic collisions, the momentum is conserved

$$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$$

Or if there is an inelastic collision (perhaps the car hit a wall of clay), we know most energy turns into heat and that the final velocity of the two objects colliding are equal

$$m_1v_{1i} + m_2v_{2i} = v_{2f}\,(m_1 + m_2)$$

Also recall that we learned how skid marks can be utilized to determine what velocity a car was traveling pre-impact in order to determine who is at fault.

$d = kv^2$ where k is a constant (depending on the car) and $k = \frac{1}{2\mu g}$

Your job is to write an investigation. How will you determine the velocity of the carts before impact for (1) a head-on collision, (2) a rear-end collision, and (3) a collision at a right angle.

APPENDIX J

PERFORMANCE-BASED ASSESSMENT:

MATHEMATICAL MODEL

Individual work: make conceptual models with the following:

Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

- Recall models (conceptual or physical) explain how something works, they are used to make predictions and/or identify patterns.

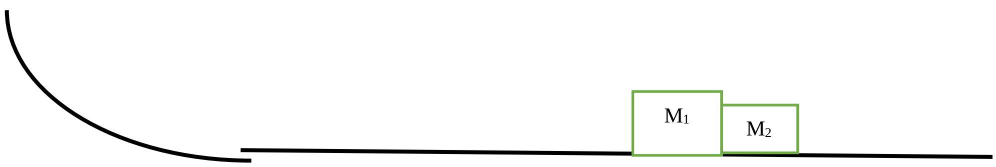
APPENDIX K

PERFORMANCE-BASED ASSESSMENT:

SUMMATIVE TEST

Harold was curious about the momentum of the two blocks in the drawing below, which was set-up in his physics class.

The block called mass 1 can be placed at different locations on a curved ramp. The block called mass two sits on a horizontal surface. For this scenario we'll ignore friction, like ice on ice.



Harold wanted to know the final velocity of the two blocks stuck together. He looked up equations and wondered which one to use. Circle the equation he should use

$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$

$m_1 v_{1i} + m_2 v_{2i} = v_f (m_1 + m_2)$

$v = at^2$

$v^2 = v_0^2 + 2a (x_f - x_i)$

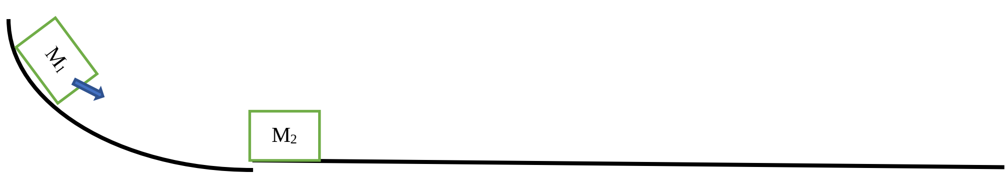
Explain why you chose that equation:

Design an experiment to graphically test the relationship between height and the two block system:

(1) equipment

(2) procedure

Then Harold wondered what the final velocity would be if the blocks bounced off each other rather than sticking together.

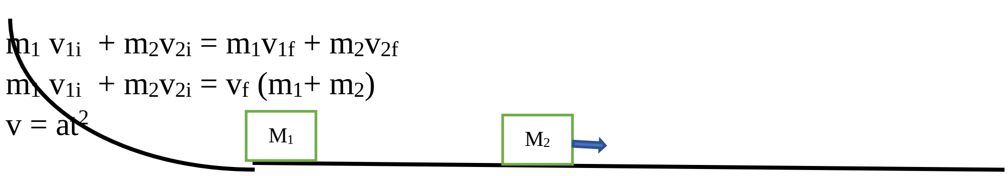


To determine the final velocity in this scenario, circle the following equation you would use

$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$

$m_1 v_{1i} + m_2 v_{2i} = v_f (m_1 + m_2)$

$v = at^2$



$v^2 = v_0^2 + 2a(x_f - x_i)$

Explain why you chose that equation:

Harold wondered if the initial velocity would equal the final velocity. or $v_1 + v_1 = v_2 + v_2$
Is this true for this scenario? Explain:

Harold set-up this scenario with equal masses that bounced off each other in an elastic collision. He released mass one and recorded the following data.

Actual speed of mass 1 after the collision (m/s)	Actual speed of mass 2 after the collision (m/s)	Predicted speed of mass 2 after the collision (m/s)
0.1	1.32	1.57
0.1	1.63	1.98
-0.02	2.11	2.43
0.0	2.53	2.71

He double checked and got the same results.
Why does the actual speed of mass 2 not agree with Harold's predicted speed of mass 2?

APPENDIX L

LIKERT SUMMATIVE SURVEY

QUESTIONS	1 Strongly disagree	2 disagree	3 neutral	4 agree	5 strongly agree
Documented problem solutions helped me critically analyze how I solve physics problems.	1	2	3	4	5
Comments:					
Documented problem solutions helped me gain confidence in solving physics problems.	1	2	3	4	5
Comments:					
Documented problem solutions helped me better understand the physics content.	1	2	3	4	5
Comments:					
Documented problem solutions helped me better recall information learned due to practice.	1	2	3	4	5
Comments:					
Performance-based assessment, in the science and engineering practices, helped me critically analyze how I solve physics problems.	1	2	3	4	5
Comments:					
Performance-based assessment, in the science and engineering practices, solutions helped me gain confidence in solving physics problems.	1	2	3	4	5
Comments:					
Performance-based assessment, science / engineering practices, helped me better understand physics content.	1	2	3	4	5
Comments:					
Performance-based assessment, science / engineering practices, helped me recall information due to practice.	1	2	3	4	5
Comments:					
Learning activities were useful and relevant.	1	2	3	4	5
Comments:					
I actively participated in my learning.	1	2	3	4	5
Comments:					
The college board unit exams were reasonable.	1	2	3	4	5
Comments:					
Overall, I am more confident in my understanding of physics content.	1	2	3	4	5
Comments:					
Overall, I am more confident in my explanations of physics content.	1	2	3	4	5
Comments:					
I learned physics content best by a method not mentioned in this survey.	1	2	3	4	5
Comments:					
Overall rating of the instructor.	1	2	3	4	5
Comments:					

APPENDIX M

NGSS COMPARISON CHECKLIST

Science / Engineering Practices	Pretest Posttest Unit 3	Pretest Posttest Unit 4	Pretest Posttest Unit 5
SEP: Asking questions and defining problems			
SEP: Planning and carrying out investigations			
SEP: Analyzing and interpreting data			
SEP: Developing and using models			
SEP: Constructing explanations and designing solutions			
SEP: Engaging in argument from evidence			
SEP: Using mathematics and computational thinking			
SEP: Obtaining, evaluating, and communicating information			
Disciplinary Core Ideas in Physical Science	Pretest Posttest Unit 3	Pretest Posttest Unit 4	Pretest Posttest Unit 5
DCI – PS1: Matter and its Interactions			
A. *Structure and properties of matter*			
B. *Chemical reactions*			
C. *Nuclear Processes*			
DCI – PS2: Motion and Stability: Forces and Interactions			
A. *Forces and motion*			
B. *Types of interactions*			
C. *Stability and instability in physical systems*			
DCI – PS3: Energy			
A. *Definitions of energy*			
B. *Observation of energy, and energy transfer*			
C. *Relationship between energy and forces*			
D. *Energy in chemical processes and everyday life*			
DCI – PS4: Waves and their applications			
A. *Wave Properties*			
B. *Electromagnetic Radiation*			
C. *Information Technologies and Instrumentation*			
Cross-Cutting Concepts	Pretest Posttest Unit 3	Pretest Posttest Unit 4	Pretest Posttest Unit 5
CCC: Patterns			
CCC: Cause and Effect: Mechanism and Prediction			
CCC: Scale, Proportion, and Quantity			
CCC: Energy and Matter: Flows, cycles and conservation			
CCC: Structure and Function			
CCC: Stability and change			

APPENDIX N

ANCHORING PHENOMENA

Gravitron ride at a carnival or fair (Wikipedia, 2022).

Weightlessness example (Wikipedia, 2022).

Energy Unit – Unit 4

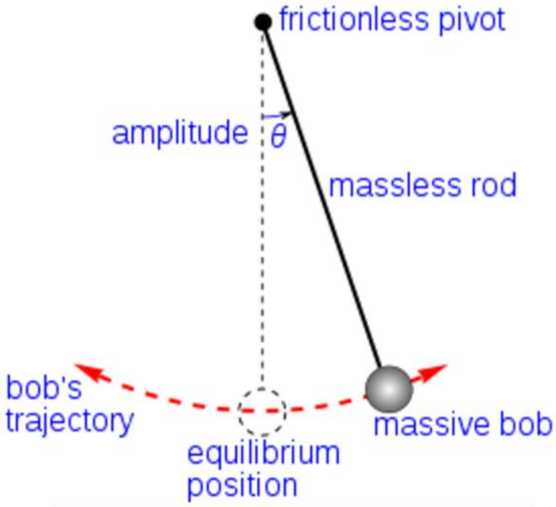
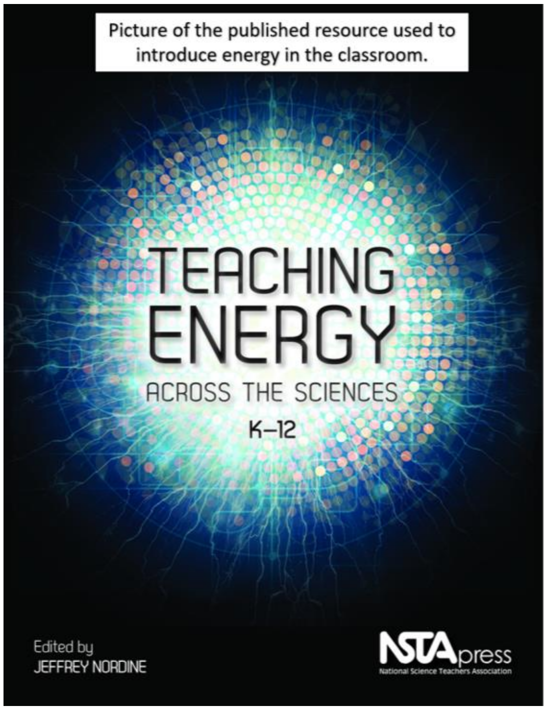


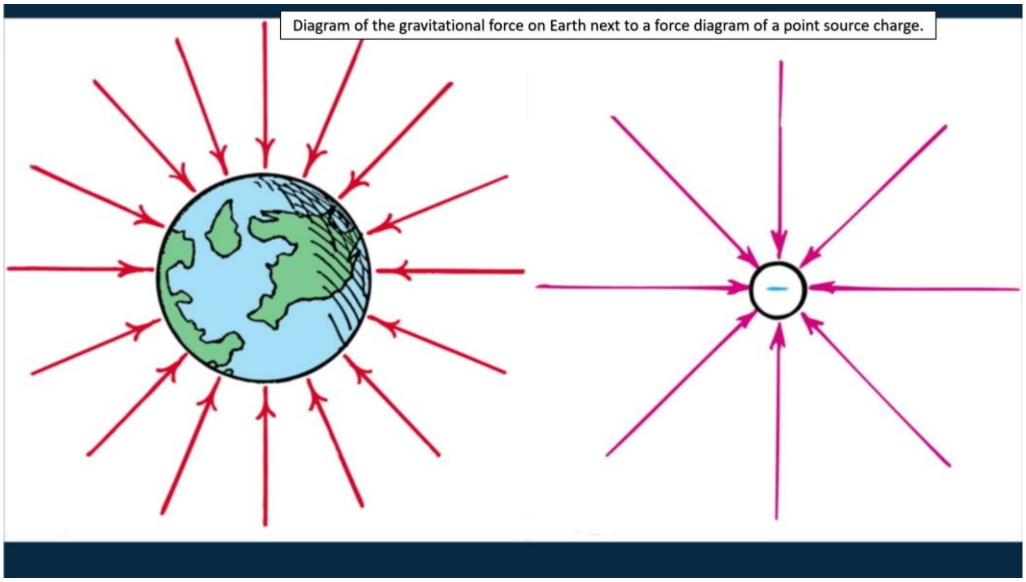
Diagram of a pendulum swinging right of equilibrium.

Pendulum example (Wikipedia, 2022).

Picture of the published resource used to introduce energy in the classroom.

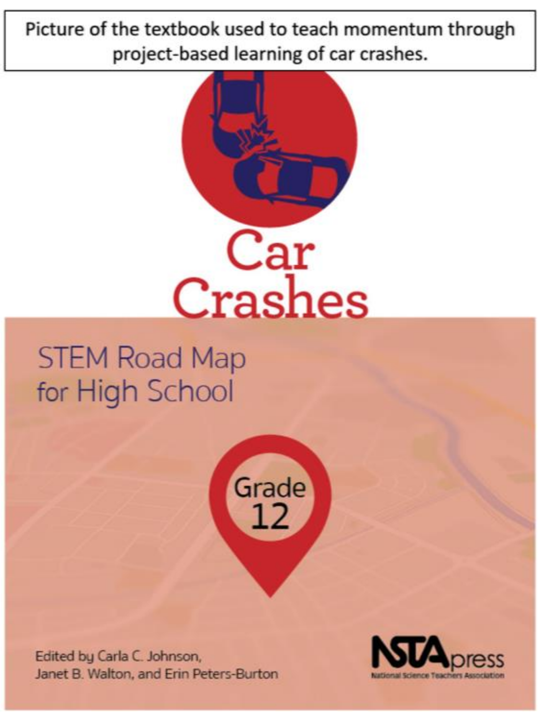


The teaching resource utilized for teaching energy in my classroom (Nordine, 2015).



Comparison between gravitational potential energy and a point source charge (Hewitt-Drew-it, 2013).

Momentum – Unit 5



Curriculum utilizing car crashes to teach momentum in a physics classroom (Johnson et al., 2018).