THE EFFECTS OF INQUIRY ACTIVITIES IN A NINTH GRADE PHYSICS CLASSROOM

by

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Mary Katherine Mingels

July 2014
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The focus of this study was on the impact of including guided inquiry activities in a 9th grade introductory physics class. Specific focus was paid to measuring the effect on student engagement, interest, and content mastery. It was also of interest whether the inquiry activities were more effective when implemented before or after direct instruction of the content.

The research covered three units of study. During the Pre-treatment unit on Newton’s 3rd Law and Momentum, students did not receive any special treatment, but rather experienced my traditional style of teaching with lectures, note taking, a few standard lab type activities, and short video supplements. In each of the next two units, the first on Work, Power, and the Conservation of Energy and the second on Heat and Heat Transfer, students were introduced to guided inquiry activities. The students were split into two research groups. In the first of the treatment units, group A received direct instruction first and group B experienced the inquiry activities prior to direct instruction. In the second of the treatment units, the two groups’ experiences were switched.

Data from class surveys, pre- and post- tests, and a mock assessment with a standardized test agreed that overall not only did students prefer the inquiry activities to the previous class structure, their understanding of the physics content was also increased. Students were more engaged while conducting inquiry activities and actually requested to do more of these types of activities. Furthermore, it was found that the inquiry activities were more effective when they followed a period of direct instruction rather than being used to introduce a topic.
INTRODUCTION AND BACKGROUND

For the past two years, I have taught introductory physics at Holbrook Junior-Junior High School in Holbrook, MA. Holbrook is a small school serving 480 students in grades seven through twelve in a small district of just over 1200 students. The population of students is somewhat diverse with 63.8% Caucasian, 19.4% African American, 5.4% Asian, 6.5% Hispanic, and the remaining 4.9% comprised of Native American, Native Hawaiian, Pacific Islander, or Multi-race students. More than 10% of the students have a first language other than English, of which the predominant languages are Haitian Creole and Portuguese Creole. Low-income students comprise 48.3% of the student population with 43.1% on free lunch and another 5.2% on reduced lunch. Only 12.9% of students are identified as having disabilities, which is below the state’s average of 17%. Over half, 55.0% of students are identified as high needs (http://profiles.doe.mass.edu/).

Holbrook is a small town about 20 miles south of Boston, MA with few business opportunities, leading to a relatively low economic class. To increase the overall number of students, our district participates in a school choice program which allows students in neighboring cities and towns the opportunity to attend. Our school has a fairly high teacher turnover rate that we are currently trying to reduce. In the 2012-2013 school year, nearly a third of the teachers were in their first year at the school. Even so, the majority of our 37 teachers personally know nearly every student in the school. Some have even known the students as long as they have been enrolled in the district, allowing for a much more individualized teaching practice and targeted lesson planning. I teach all five sections of the introductory physics course offered primarily for 9th grade
students. Being the sole physics teacher in the district, I have a lot of flexibility in how and what I teach.

One of the primary initiatives in our district is to increase our student performance on the Massachusetts Comprehensive Assessment System (MCAS) tests. In the spring of 2013, none of my current students scored advanced on the grade 8 Science and Technology/Engineering MCAS Exam. Of the 106 students who took the exam, 25% scored proficient, 62% scored needs improvement, and 13% were in the warning/failing category, which was an improvement over the previous year. In the 2013-2014 school year, I was challenged to push these same students towards our goal of a 100% passing rate on the grade 9 Introductory Physics MCAS Exam. Additionally, we strove to push our students to have a higher than state average number of students scoring in the advanced category. We had several meetings to discuss the test results, study the data, analyze the tests and commonly missed questions, and discuss the pacing of the course.

In the spring of 2013, we implemented an after-school Bulldog Academy MCAS preparation session two days per week, but had very irregular attendance. We re-organized and re-structured this program in the spring of 2014 to improve its impact. My student learning goal was to increase performance on this exam through increased practice specifically focused on the students’ writing abilities, critical thinking skills, and confidence in attempting the open-response questions on the exam. Based on past student MCAS performance as well as in class performance, student motivation, and engagement, our focus fell predominately on the college preparatory (CP) students, though our efforts were directed at honors as well and most of the extra support that was offered to the CP students was also available to those in honors.
In the summer of 2010, I attended summer courses at the University of Washington where we were introduced to the implementation of inquiry practices in physics education. Specifically, we participated in a series of inquiry activities from the perspective of our own students on the topics of kinematics, dynamics, and electricity.

Prior to teaching in Holbrook, I taught in other districts and in the years since taking these courses I attempted to implement pieces of what I had learned. Unfortunately, my efforts were met with very limited success for a variety of reasons. I often tried to modify the activities we conducted in my classes without much consideration for the specific needs of my students. After several failed attempts, I abandoned nearly all of the inquiry activities and returned to my comfort zone of traditional lecture and practice based teaching with minimal laboratory activities posing as enrichment.

While I seemed to have moderate success in my teaching, I still felt like I could do more. In my first year at Holbrook, I struggled with the same moderate discipline and engagement issues that had plagued my classrooms from my first teaching position. Things were going ok; I wanted them to be exceptional. I wanted students to leave my classroom no longer begrudging science class, but looking forwards to their next session. So, I began to reevaluate my methods. I kept coming back to inquiry as I really believed it might be the change I was looking for. In many of our department meetings, there was significant talk about “spoon-feeding” our students upon which we agreed they were now overly dependent. If only I could engage them in their own learning, perhaps I could encourage them to become more active learners.

Towards this end, I went back to the inquiry activities we did at the University of Washington and I began to look into what made them inquiry activities. I had been
falling victim to the notion of inquiry as a linear strategy following the scientific method (Zak, 2013). I researched what inquiry truly meant. Scientific inquiry is not a set practice. There are many ways to approach it. Inquiry refers to activities where students approach learning in a way more similar to how a professional scientist would, posing questions and proposing explanations based on evidence they collect (National Research Council, 1996). Scientific inquiry requires students to learn how to ask questions and devise methods to answer those questions. I came to the realization that while the activities I had attempted had not worked very well with my students, it did not mean that my students could not learn by inquiry. I realized it was the method of teaching that was important, not the specific activities and that any of the laboratory activities that I currently conducted with my students could potentially be modified to fit the inquiry methodology with a concerted effort. While I felt my students would still require direct instruction to supplement these activities, and worried the incorporation of inquiry might require a slow evolution to ease them into the practice, the prospective learning gains from their inclusion drove me to invest in them as a potentially superior teaching strategy.

I decided that I wanted to redirect my attempts at including inquiry in my classroom. Previously, I had done so in a cursory manner, including inquiry activities whenever they seemed to fit without much preparation. I hoped that with more preparation and more regular inclusion, I could modify lab activities that had actually proved fairly successful in my classes to better fit the inquiry model. I endeavored to have greater success implementing them to improve the students’ overall classroom experience and achievement. This lead to my research question, What is the impact of
using inquiry activities in a high school physics class? The following sub-questions were researched.

1) Does student engagement and interest improve from the use of inquiry activities?
2) Is student understanding of content improved by the use of inquiry activities?
3) Are inquiry activities more effective when used before or after direct instruction?

CONCEPTUAL FRAMEWORK

Science and technology are more important for students’ continued success today more than ever before. Yet students’ performance in the sciences is worse (Singer, Hilton, & Schweingruber, Eds., 2005). One of the flaws found in our educational system was the lack of understanding of what constitutes a science laboratory. Too often the science laboratory is given the limited definition of a room with special scientific equipment where students perform carefully written procedures, following step by step instructions, to verify a predetermined result that supports a lesson they have already learned about in class. Llewellyn and Rajesh (2011) caution against overemphasis on the traditional scientific method and encourage educators to focus more on real scientific work. To be more successful in introducing students to the nature of science inquiry and enhancing their science learning, laboratories must be pushed beyond this definition with more concrete goals of science in mind. Zion and Mendelovici (2012) categorized this first approach to science as structured inquiry and compare it to the more active approach of open inquiry. The current state of science education tends to fall more on the former, but can be improved (Chabalengula & Mumba, 2012).
Zion and Mendelovici (2012) describe structured inquiry as the standard process of asking a question, collecting data, and drawing a conclusion based on that data. This leaves out the rest of the inquiry process including inference; understanding the distinction between a hypothesis, a theory, and a law; and the correlation between ideas and evidence. Since structured inquiry is based primarily on experiments where the results are known before the test is conducted, it is inadequate in preparing students for real scientific practices.

Zion and Mendelovici (2012) continue to describe an intermediate form of inquiry instruction called guided inquiry whereby students work collaboratively to decide their own process to investigate the question asked of them by the teacher. Though the answer may not be known by the teacher prior to the investigation, since the question and often the actual procedure are still dictated, the level of uncertainty is decreased. This can have positive results for both the students and the teachers. The study elucidates though, based on significant prior research and twelve years of implementation, how open inquiry can stimulate students and will better prepare them with the skills needed for success. They also found that the students who participated in this open inquiry demonstrated more ownership of their education and took more responsibility for their activities in the same way a professional scientist would.

The concept of inquiry has been a focus in science education for many years now, however there remains a lack of thorough understanding of the true nature of scientific inquiry (Llewellyn, 2013). Inquiry is a general term for asking questions and seeking answers, a process that can be applied in any subject area. Science inquiry is the term better suited for the type of inquiry based on specifically science activities focused on
answering a specific question. Scientific inquiry is the more in-depth form of inquiry that focuses on critical thinking and reasoning of an actual scientist. Inquiry requires students to go beyond the scientific process to develop an understanding of the nature of science. Inquiry is more than just a hand-on lab experience. True scientific inquiry requires an understanding of how real scientists work and should be based on evidence and explanations (Llewellyn & Rajesh, 2011). To maximize scientific literacy, inquiry activities should be reinforced with argumentation that allows students to develop their reasoning skills to analyze the data they collect and use that data to accumulate evidence to defend their claims.

The use of inquiry practices is of paramount importance in science, more specifically in the secondary physics classroom where many students enter with a preconceived opinion that science is too difficult, boring, and useless to begin with (Kock, Taconis, Sanneke, & Gravemeijer, 2013). There are numerous theoretical and abstract concepts for students to learn in physics, many of which are difficult to even view. A study focusing on electricity education through inquiry activities found limited success and noted three tensions: one between open and guided inquiry, another between students generating their own ideas and conclusions and learning accepted scientific theories, and finally, between fostering interest and engagement in science and the task-oriented culture of most schools.

When directly compared with lecture and demonstration, students were found to be significantly more engaged during inquiry based activities on the same topics (Molotsky, 2011). During these activities, if a student was having trouble, the teacher could give one-on-one support while other students continued their investigations,
prompting higher overall success of the class. Positive changes in student attitude were recorded and it was revealed that students were not only more engaged in their learning, but they also grew a greater personal interest for the subject and were better able to relate their learning to real world applications.

Norris, Phillips, and Osborne (2008) discuss the shortcomings of many secondary science education classrooms and suggest a method for emphasizing scientific inquiry that improves the level of student learning in those classrooms. They illustrate a common view of learning whereby students read from a text and answer questions based on their reading. With this, they demonstrate that while students may be able to answer all the questions asked about the text, they still have no actual understanding of the topic that they read. They show how a focus on interpretation and argumentation can be used to teach inquiry skills and will lead an enhanced depth of understanding. By posing a question that many students may already think they know the answer to from prior science classes, the methods of inquiry can be demonstrated to students. Subsequently, the students will be more actively engaged in the process of understanding even fundamental scientific principles. Once the process of inquiry is learned, it can then be applied to all areas of a student’s education. Furthermore, they emphasize the importance of student experience with extended inquiries to show students the challenges of reaching scientific conclusions. Focusing on depth rather than breadth of understanding and allowing students to feel perplexed will better prepare them for their futures as learners. Two major benefits of teaching inquiry are the collaborative nature and the real world connections (Pifarré, Wegerif, Guiral, & del Barrio, 2012).
A case study done by Molotsky (2011) found that the teacher must be engaged in the inquiry activity if their students are to succeed. A study of secondary science teachers identified five major barriers to teaching inquiry in a science classroom (Roehrig & Luft, 2004). The first was a lack of thorough understanding of the nature of science and scientific inquiry itself, a fundamental requirement for proper inquiry instruction. The next two involved a lack of knowledge of actual science content and pedagogical content. The fourth focused on individual teaching beliefs. The final barrier was teacher concerns about their classroom management and students during inquiry activities. The study emphasized the need for better teacher preparation prior to entering the classroom and more support for current science teachers to ensure they have the requirements to implement their curricula.

Chabalengula and Mumba (2012) found similar barriers to teaching inquiry, including a narrow conception by teachers of what constitutes inquiry; a discrepancy among teachers and in syllabi, textbook and assessments in the coverage of different levels of inquiry; and too high an emphasis on the more basic forms of inquiry tasks. Zak (2013) found that when pre-service science teachers were asked to relate key terms from scientific inquiry in a concept map, they held a very linear view that closely resembled the scientific method, and that this view of inquiry can act as a barrier to student learning and engagement. Another study of pre-service science teachers showed the challenges they face crossing the border from veteran science student to novice inquiry science teacher (Kang, Bianchini, & Kelly, 2013). It highlights the importance of offering teachers explicit opportunities to navigate this border including chances to participate in inquiry investigations themselves to deeper understand the concept of inquiry.
Many of these barriers affect the willingness of the teacher to take the time to actually prepare and institute inquiry activities. When the materials for an inquiry activity are not prepared, the activity is not fully planned, a teacher does not attempt the activity in advance, or a teacher does not participate fully in the activity during class the results are evident (Molotsky, 2011). The success of the activity is diminished and students will be lost. This supports the importance of better preparing teachers for teaching inquiry as well as familiarizing them with the research that proves the established benefits of inquiry education.

The major goal of science education is to ensure that students appreciate and have a deep enough understanding of science to participate in public forums, and that they have the skills to question science and pursue their chosen careers (National Research Council, 2012). While it is said the educational system in the United States currently fails to reach these goals, through the implementation of inquiry based science education we can begin to work towards remediating that failing (National Research Council, 2012; Chabalengula & Mumba, 2012).

METHODOLOGY

Beginning in November 2013, the effects of including structured and guided inquiry activities on student engagement and performance were investigated in my four sections of college preparatory (CP) introductory physics classes consisting primarily of ninth-grade students ($N = 62$). Overall, across the CP sections, there was approximately the same number of male and female students. While the majority, 85%, was in the ninth-grade, the academic abilities and backgrounds were diverse. 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).

To decrease the effects of student ability or class composition, there were two subject groups. Each group consisted of two college preparatory sections and both groups were subject to the same Pre-treatment unit. The class sections contained a mixture of students diversified by academic ability as well as by gender, grade level, age, and ethnicity. Each group had an equal number of students ($n = 31$).

In the Pre-treatment unit for both sections, the Newton’s Third Law and Conservation of Momentum Unit was the focus. This unit followed my standard teaching practice. I began all units with pretests to determine background knowledge and understanding and to identify any misconceptions. Prior to introducing the unit, I administered the Newton’s 3rd Law and the Law of Conservation of Momentum Pre-test (Appendix B). Each unit pre-test consisted of up to 25 multiple choice questions taken from the Prentice Hall Science Explorer Series, Massachusetts Comprehensive Assessment System (MCAS), teacher generated questions, and a variety of other sources and were compiled based on the Massachusetts State Frameworks for Science Education (Massachusetts Curriculum Frameworks, 2006). The questions focused primarily on concepts rather than mathematical relationships. They were administered in-class using Scantron technology for consistent grading. The scores on the pre-tests were averaged across each class and treatment group and used for comparison against the same questions given post-instruction. Students were not privy to their pre-test results and the tests were not handed back to prevent students from trying to memorize the questions.
Each topic within the unit began with a reading assignment for homework to give the students a general understanding of the unit’s content. This was followed by direct instruction with a PowerPoint style lecture and guided notes. Only major topics were followed by standard laboratory activities or teacher demonstrations such as dropping two objects with different masses to demonstrate the effect of gravity. Two to three short videos were used in each unit to support instruction and to accommodate more visual learners. The unit ended with the Newton’s 3rd Law and the Law of Conservation of Momentum Post-test (Appendix C). The tests were graded using an exam key and open response rubric to ensure unbiased scoring of student responses.

I utilized pre and post-tests in all units of study, such as the previously mentioned Newton’s 3rd Law and the Law of Conservation of Momentum Pre-test and Post-test, to measure the amount of content knowledge students had actually learned as a result of instruction and to compare student understanding of that content matter (Appendices B through G). The multiple choice section of these tests included the same questions from the pre-tests, although the order of the questions was scrambled. The results were averaged across each class section and research group. The results of each pre-test were compared numerically with those of the multiple choice portion of the post-test to measure the increase in subject mastery. The post-tests also included multiple open response or short answer questions pulled from the same sources as the pre-test to gain a deeper view of student understanding. In addition to analyzing the improvement via percent change from pre-test to post-test on the multiple choice portions, I also compared the overall scores on each unit test including the open response questions. The results were compared between the two subject groups and across each treatment to determine
the impact of each treatment on student success. I employed formative assessments and quizzes at various times throughout each unit, however the results of these were not included for the purpose of this study since they were used more to inform instruction than to directly measure learning (Appendix H). Although students were encouraged to complete test corrections to enhance their understanding, correct their misunderstandings, and improve their scores, all scores analyzed from the unit exams were the original scores upon first implementation of each assessment.

While teaching, I recorded qualitative information on student interest, engagement, and success based on observations of student participation, student quotes, observations made by my co-teachers, and notes on progress throughout the lessons. Both groups of students were subject to these control constraints simultaneously so that their results could be compared. This gave me a baseline which allowed me to measure the degree to which adding inquiry activities improved student performance and engagement compared with my normal teaching strategy.

During the first treatment unit on Work, Power, and the Conservation of Energy, the two groups had different classroom experiences so as to avoid any bias from content difficulty. In this unit, Group A received direct instruction prior to completing any inquiry based activities; while group B completed the inquiry activities prior to any direct instruction. I chose to focus on the more structured guided inquiry type activities due to my students’ lack of prior experience with the inquiry model. For this unit, I employed computer simulations as well as station labs and a human work and power activity in which students determined the amount of work required for them to climb a set of stairs. Each of these activities was based on the guided inquiry model in which students learned
about the science concepts by completing activities, asking questions, and developing their own ideas. Throughout each, I circulated amongst the students asking guiding questions and providing support where necessary. In the second treatment unit on Heat and Heat Transfer, the two groups were reversed (Table 1). In this unit I also included a whole class inquiry activity where students were called forward to make predictions about and then experience different situations and try to explain to or discuss with the class what was occurring. For example, students were given a bimetallic bar, a jar of ice water, and a lit candle. The bar was passed around the room and students were asked to make observations about it, predict what might happen if the bar was heated or cooled, test it, and then try to explain what happened. After this, they were asked what the purpose of something like this might be in an attempt to teach them about the real world applications. Guiding questions and frequent teacher check-ins were used while students completed the inquiry activities to measure their understanding and progress.

![Units of Study and Study Groups Diagram]

*Figure 1. Treatment Summary.*
A variety of assessment and data collection tools were implemented throughout the three units of the study in addition to the pre- and post-tests to compare indicators of enhanced learning and engagement (Table 1). To fully gauge these, I employed a combination of qualitative and quantitative techniques to collect the maximum amount of data on my students’ learning. I compared the data from each both across the subject groups as well as across the different units.

Slight variations of the Physics Understanding and Engagement Surveys were implemented at three different times during this study (Appendix I). The first was given to all students at the end of the Pre-treatment unit. It was administered using the online survey and quiz resource Socrative.com to which the students were already familiar as a formative assessment tool. This website allows students to answer questions on either a mobile device or a computer both during and after school. The results are downloaded into an excel worksheet where I was able to separate the student’s names from their responses prior to analysis to maintain anonymity (names were collected initially to ensure each student only answered each survey once). Each question is presented to the student individually and a variety of multiple choice and open response question formats are supported. The survey contained a series of questions using a Likert scale to assess the student responses, ranging from one for agree completely to five for strongly disagree, which allowed me to compare student engagement and interest in the content matter. These also allowed students to self-report on their understanding and confidence in the subject matter. I averaged the responses for each question to use as a baseline for comparison against the same questions given after each treatment. I administered slightly modified versions of this survey after the first treatment unit with added questions
specifically focused on the inclusion of inquiry activities. I administered the survey for a third time about two weeks after the completion of the final treatment unit when all students had undergone both treatment scenarios and had some time to reflect.

The number of students participating in each survey varied based on overall student response as keeping with the guidelines for student research it was made clear to the students that participation in the research surveys was voluntary and would not affect their grade or standing in any way. This caused multiple students to choose not to participate in each of the surveys. Additionally, the online delivery of the surveys themselves may have dissuaded some students who would otherwise have chosen to participate. Finally, the sample size for each survey was based on the total number of students the survey was administered to. The Physics Understanding and Engagement Pre-Treatment Survey was opened to all 62 of my CP physics students, of whom, 34 completed the survey in full. The Inquiry First and Instruction First variations of the survey were utilized after the first treatment unit in which the two research groups received different experiences. Group A received direct instruction first while group B underwent the inquiry activities prior to instruction. These surveys only varied by a few questions, however I chose to include their results separately to determine whether the treatment order might affect the student’s opinion. Since each of these treatment surveys was given to a different treatment group, the total number of students who were given each of the surveys was 31 out of the total 62 students. Out of these, only 30 students in group A completed the survey in full and 26 students in group B completed the survey in full. The final Post-Treatment Survey was administered a short time after all treatment
units had been completed. It was again offered to all 62 of the students since all had now undergone both treatment experiences, of whom 47 completed it in full.

For the questions that were included on multiple surveys, I utilized percent change to compare the results from the Pre-treatment survey to the surveys given after each treatment unit. On inquiry specific questions which were not on the Pre-treatment survey due to students’ lack of prior experience with inquiry, I directly compared the results between each treatment group and with the Post-treatment survey results. I focused my analysis on the percent of students who selected agree completely or somewhat agree to each of the survey questions. The surveys each ended with a set of three open-response questions about how the way concepts were taught has affected their learning, any suggestions they might have, and anything else they would like for me to know to allow students to include more of their own input. Their responses to these questions were used to reinforce the more quantitative survey data and test score analyses.

Since this is a MCAS subject, the Spring 2013 Introductory Physics MCAS (XX. Introductory Physics, 2013) test, taken for practice for the coming spring examination, was also utilized as an additional data source for measuring student understanding (Appendix J). The test was administered in March of 2014 after students had completed both treatment units and had finished the majority of their primary instruction for the course. Students had not, however, yet received thorough instruction in the last unit of study, waves and the electromagnetic spectrum, nor had they had the same formal MCAS review as the students who took the exam in 2013. They took the test as a Mock MCAS exam, proctored by myself and fellow teachers following the strict MCAS testing
constraints to best reproduce the results of an actual MCAS test. Students had access to the same MCAS formula sheets, calculators, and graphic organizers that would be available to them during the actual MCAS exam. The test consisted of 40 multiple choice questions and 5 open response. The multiple choice questions were graded using the same Scantron technology as my unit tests. The open response items were carefully assessed on a zero to four point scale following the MCAS scoring rubrics and sample scoring guides. The multiple choice and open response scores were combined and a score conversion chart was used to convert the raw scores into scaled scores and to be placed into the proper scoring ranges or *Advanced, Proficient, Needs Improvement*, and *Failing*. The results of this test were compared against the results from my previous year’s students. I used them as a baseline to create a comparison against students who had not participated in any of the treatment activities but had rather experienced a full year of my standard teaching practice.

Table 1
*Data Triangulation Matrix*

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Data Source 1</th>
<th>Data Source 2</th>
<th>Data Source 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Does student engagement and interest improve from the use of inquiry activities?</td>
<td>Student Surveys</td>
<td>Qualitative observations of student participation</td>
<td>Co-teacher Observations</td>
</tr>
<tr>
<td>2. Is student understanding of content improved by the use of inquiry activities?</td>
<td>Teacher created Pre-tests</td>
<td>Teacher created Post-tests</td>
<td>Practice MCAS Exam</td>
</tr>
<tr>
<td>3. Are inquiry activities more effective when used before or after direct instruction?</td>
<td>Teacher created Pre-tests</td>
<td>Teacher created Post-tests</td>
<td>Student Surveys</td>
</tr>
</tbody>
</table>
DATA AND ANALYSIS

Only 31% of students responding to the Physics Understanding and Engagement Pre-treatment Survey answered *agree completely/somewhat agree* to a statement about them liking physics class \((n = 34)\). However, 53% of the students agreed they understood the content and 56% agreed that by the end of the unit they had learned a lot. Forty-seven percent of students felt the ends of unit tests were easy, and 44% of students felt the class was being well prepared to succeed on the MCAS Physics Exam they would take in June. The sample sizes of each of the surveys given vary due to student participation. Additionally, the After Instruction First Survey and the After Inquiry First Treatment Survey were each only administered to the two treatment groups, A and B respectively, and therefore each was only offered to 31 of the total 62 students participating in the study. The four major themes from the surveys were used to analyze the students’ responses about their experience in physics class as well as their overall success in physics (Figure 1).

*Figure 2.* Common themes from the Physics Understanding and Engagement Surveys.
Comparing the Pre-treatment and Post-treatment Physics Understanding and Engagement Surveys, after the inclusion of inquiry activities, there was a 44% decrease in the number of students reporting that they were often bored during class (Figure 3). In other areas of engagement and initiative there was little change in students’ self-assessments from the surveys. Over 80% of all students responded either somewhat agree or agree completely when asked whether they participate with their groups in class on all of the surveys, but only 30% or fewer reported that they come afterschool for help when they don’t understand something. A student actually admitted that they think they “would do better had I come after class more often and payed more attention.” One student said, “when we work in groups I understand easier” and suggested, “we could do more group work” when asked how the way concepts were taught has affected their learning and whether they had any suggestions for improving class. Another student said that he “like(s) doing things together as a class,” while a third suggested “more group work and more labs.”
Figure 3. Percentage of students responding agree completely/somewhat agree to questions about engagement and initiative.

From the Pre-treatment Survey to the After Inquiry First Treatment Survey, there was a 31% increase in the percent of students who agreed completely/somewhat agreed that their questions were answered pretty quickly, and when compared with the After Instruction First Treatment Survey, there was a 57% increase (Figure 4). There was a bit of a drop in the percent of students who said they learn more from working in groups than from lectures and taking notes from the Pre-treatment Survey to each of the treatment surveys, however the percent went back up in the Post-treatment Survey when students were able to reflect on the year as a whole. One student reflected that he would have liked more “hands-on experience to understand better in class,” and another stated, “When I work in groups I get things more than reading in the book.” Overall, 26
students, out of 47, requested more group work when asked post-treatment if they had any suggestions for improving class.

Figure 4. Percentage of students responding agree completely/somewhat agree to questions about the teaching methods I employ.

On the Post-treatment Survey, 79% of students answered agree completely or somewhat agree when asked whether they preferred the inclusion of inquiry activities better than the typical class structure we used at the start of the year and 77% felt like they had learned a lot from doing the inquiry activities (Figure 5). The percent of students who felt more engaged during lectures or while taking notes as a result of the inquiry was not as high, only 49%, but 70% reported that they would prefer to do more of the inquiry activities anyway. On all of these questions except the engagement during notes, the percent was higher when students were asked following the unit where they started with instruction and the inquiry came later as a reinforcement activity than when the inquiry activity preceeded the direct instruction. When asked how the way concepts
were taught affected the student’s learning, one replied, “I learn best when given visual representation and have actually used most of the things I learn in this class in my daily life, personal projects, research, and theories because of the way they were presented in the real-to-life inquiry activities.”

![Graph showing percentage of students responding to questions about the inclusion of inquiry activities.](image)

**Figure 5.** Percentage of students responding *agree completely/somewhat agree* to questions about the inclusion of inquiry activities.

There was a 54% change in student enjoyment from the After Inquiry First Treatment Survey to the After Instruction First Treatment Survey and an overall response of 70% of students who *agree completely or somewhat agreed* to enjoying the inquiry activities on the Post-treatment Survey (Figure 6). There was also a drop in the percent of students who felt confused, bored, or frustrated during the inquiry activities. One student acknowledged after the instruction first treatment, “The more notes we take, the more I understand what is being taught during the inquiry activities.”
Figure 6. Percentage of students responding agree completely/somewhat agree to questions about their feelings towards the inquiry activities.

Overall feelings about the class mostly stayed the same or improved as a result of the inclusion of inquiry activities as well. Although the percent of students who agree completely/somewhat agreed on the After Inquiry First Treatment Survey was lower, there was a 45% increase from the Pre-treatment Survey to the Post-treatment Survey in percent of students who felt like they understood what was being taught throughout the unit (Figure 7). The percent of students who felt like they had learned a lot and who felt they were prepared for the Spring 2014 MCAS Physics Exam also increased. There was little change in the percent of students who found the tests at the end of the unit to be easy, however in Figures 8 and 9, it can be seen that their overall test performance did improve from the Pre-treatment unit. And while the percent of students who admitted to
liking physics class remained slightly below 50%, it too increased from the Pre-treatment Survey.

Figure 7. Percentage of students responding agree completely/somewhat agree to questions about their overall class experience and understanding.

There were mixed results when comparing the overall scores of students on the end-of-unit exams after the Inquiry First treatment to the Pre-treatment exam scores. The two groups received the same two treatments, Inquiry First and Instruction First, on alternating units to reduce the influence of the difficulty level of each unit’s primary concepts. Group A, who received the Inquiry First treatment during the heat unit showed a slight, two percent, decrease in their overall test scores from the Pre-treatment unit; while group B, who received the Inquiry First treatment during the energy unit showed a slight, four percent, increase in their overall test scores from the Pre-treatment unit (Figure 8). There was a greater difference, 6% increase for group A and 11% increase for
group B, when the overall results of the Pre-treatment exam and the Instruction First exam were compared.

Both groups received the same Pre-treatment experience during the Newton’s Third Law and Conservation of Momentum unit. During this unit, my standard teaching practices were followed without the inclusion of inquiry activities. This was done to allow for the comparison of student success. In the Pre-treatment unit, group A had a slightly higher average combined multiple choice and open response score the end of unit exam. Overall, the Inquiry First treatment showed little to no improvement in student learning as group B showed improvement in their end of unit exam scores, but group A showed a decline. Both groups showed improvement when instruction was supported by follow-up inquiry activities in the Instruction First units. These results are amplified when it is noted that group A’s lowest average occurred during the Inquiry First treatment, and group B’s highest average occurred during the Instruction First treatment, both of which occurring during the same unit, Heat and Heat Transfer. This means that
both groups received the same instruction and completed the same inquiry activities, simply in opposite orders which resulted in a marked difference in student success.

There was an increase in the percent change from Pre-test to Post-test for both treatment units when compared to the Pre-treatment unit (Figure 9). Unlike the scores in Figure 8 which showed the average overall end of unit exam scores including all multiple choice and open response questions for each group, these scores only include the multiple choice questions on each exam so they may be directly compared with the Pre-tests taken at the start of each unit. The greatest improvement was an 83% increase from Pre-test to Post-test when group A received instruction prior to the inclusion of inquiry activities during the energy unit. Without the inclusion of inquiry activities, during the Pre-treatment unit, group A only showed a 48% improvement from Pre-test to Post-test. Group B also showed their greatest improvement from Pre-test to Post-test when they received instruction prior to the inclusion of inquiry activities with an 80% increase during the heat unit. One student said that the inclusion of the inquiry activities “makes learning things a lot easier. When things are as organized and planned as they are, it is much simpler to focus and understand.”
Figure 9. Percent change from average pre-test to average post-test scores.

The average overall percent scored on the 2013 MCAS exam taken in June 2013 by students who had not been subjected to any inquiry treatment was six percent lower than the average overall percent scored on the same exam taken as a Mock MCAS in March 2014 by students who had undergone both treatment units but had not yet had any official MCAS review. There was a 21% increase in percent of students scoring in the advanced bracket on the exam and a 44% decrease in the percent of students who failed the exam (Figure 10). One student explained this increased success by saying, “I think that because the concepts that are being taught are presented in many different ways, such as notes, inquiry activities, demonstrations, etc., it leads to better understanding and retention.” The same student went on to say, “I appreciate the amount of thought and effort that is put into helping us learn.”
Figure 10. Comparison of student performance on the actual 2013 MCAS Physics exam with the same exam taken in 2014 as a Mock MCAS.

**INTERPRETATION AND CONCLUSION**

My research question was about the impact of including inquiry activities in my physics teaching. I focused my analysis on student engagement, interest, and understanding of content. When the students were asked directly, the percent who agreed completely or somewhat agreed that they were often bored in class dropped by 44% from the Pre-treatment to the Post-treatment surveys. Students often complain that school is too boring, so to me this is a good first sign that they did in fact find the inquiry activities more engaging. Additionally, the survey data showed a lot of evidence of students not only wanting to continue doing inquiry activities, but actually a desire to complete more of them or to complete them more often. I believe they enjoyed the break from the way the majority of their classes are taught and the opportunity to actually think through what they were being taught rather than simply recording information spouted at them in lectures.
Throughout the study, I was able to note a few interesting, albeit qualitative, observations of my students. From a failed attempt at engagement tracking via a classroom observer, I noticed that the students who tend to be considered the worst troublemakers also participated the most frequently in class. Although their responses were approximately equally split between asking questions, answering questions, and speaking out of turn to a classmate, I began to think that perhaps this extra desire to be heard in class could be channeled into more productive participation. During one of the heat inquiries, I called upon one of these students to come up and test out some heat scenarios for the class and try to answer the class’s questions about what was going on. He volunteered enthusiastically and very actively sought to impress his classmates by not only doing the activities I had laid out for him, but also to answer every question they had about it. While this was only one instance of noted success, it emphasized for me the impact a good activity can have on transforming a typically disruptive student into a class leader.

My third sub-topic was about whether inquiry activities were more effective before or after direct instruction. I did not feel confident replacing instruction altogether with inquiry based learning alone, and after reviewing my results I think that was a wise choice. In all respects, the inquiry activities seemed to have more of an impact when they were preceded by direct instruction. I think previewing the material for them in a lecture format they were familiar with gave them more confidence going into the inquiry setting and allowed them to draw better connections between the activities and the lessons being taught through them. As students become more familiar with the inquiry model, I may be able to stray further from the guided inquiry to more open inquiry methods, and I may be
able to introduce topics with inquiry more often, but for now, lecture first seems to be the way to go for my students who have had little to no prior experience with this form of learning.

The final focus of my analysis was on understanding of content matter. The gains in overall test-scores were admittedly small, only a few percent from the Pre-treatment exam to the Post-treatment exams. However, that there were gains in the overall scores when compared with the Pre-treatment exam scores on all but group A’s Inquiry First Treatment Post-test, the heat unit, is a positive sign. Additionally, the percent change from Pre-test to Post-test scores for all of the units including the heat unit for group A, did increase, indicating that perhaps this was simply a more difficult unit. According to the comparison of percent change, the students still learned more during this unit than they had in the Pre-treatment unit. Furthermore, I believe that any gain in understanding, even a small one, is a step towards increased mastery. Their performance on the Mock MCAS exam showed the greatest evidence for this increased understanding and gave me significantly increased confidence in how these students will perform on the actual MCAS exam. While there are potentially other compounding variables that might have affected their performance, that they out-performed my students from the previous year who were excluded from the inquiry treatment but who had received the full year of instruction including direct MCAS review and practice, is a fairly significant indicator of increased content understanding.

VALUE

As seen in the survey data, test scores, student quotes, and personal observations, this study had a definite positive impact on my students and my classes as a whole.
Students were more engaged in the lessons and were left wanting more in terms of the inquiry activities I introduced them to. I had been nervous to implement these as a common complaint in my school is that the students are too reliant on the so-called “spoon-feeding” of information. They want their questions answered; they want to be told. I have been accused by students in the past of “not-teaching” something if it did not come in the form of a traditional lecture where I required students to listen quietly and take notes, so I honestly did not know how they might respond to a situation in which I laid out the scenario for them, but made them ask questions and come up with answers based on their investigations. I was excited to find that students seemed more involved, and at least qualitatively it seemed that even some of the typically quieter students were finding significantly more ways to participate.

While the inquiry activities required more planning, supplies, and set-up and clean up time, I really do feel they were well worth it in the end, both for my students as well as for me as the teacher. During the activities, it was a nice sort-of break to not be the center of attention for a while. It was extra rewarding to get to circulate the room and work with the students more one-on-one, or at least one on two or three, and more directly interact with the students. I think this may have also contributed to their enhanced understanding as they were able to ask more of their questions without focusing the entire class’s attention on themselves.

Furthermore, the process of completing this study has made me a much more reflective teacher. I used to only put minimal thought into planning my lessons beyond the actual content of the lessons themselves. I considered what I wanted my students to learn, not how I wanted them to learn it. I also rarely stopped to consider student
enjoyment as a factor in my lessons. I mean, school is not to be enjoyed, but rather to educate and prepare for life, right? But coming through this process, while I am still not focused, despite my students’ requests, on making class “fun” per se, I am more cognizant of students’ feelings and interest and the role they play on student learning. When students were engaged and interested in the inquiry activities, we had almost no behavior problems, students who frequently would chose to do nothing in class were participating, and students came out of them with more content knowledge. Even now that my official research is finished, I find myself putting a lot more conscious thought and effort into planning more engaging lessons, including more inquiry activities, and generally thinking about how to maximize student interest. I do still feel there is a time and a place for direct instruction as evidenced by my students elevated level of success when the inquiry activities were preceded by instruction, but I have now been re-working my PowerPoint lessons to be more interactive and even to be more visually appealing with more pictures, video clips, and gifs.

If you entered my classroom and observed my teaching before and after I completed this research process, you might not believe I was the same teacher. Paired with the other classes I took along the way, I have grown in both my actual content knowledge and depth of understanding, but much more importantly in my pedagogical approach to teaching. I have learned the focus of school is not only on content knowledge but the experiences that engage the students to value their education and take ownership of their learning.
REFERENCES CITED


International Conference on Cognition and Exploratory Learning in Digital Age, 139-146.


APPENDICES
INSTITUTIONAL REVIEW BOARD  
For the Protection of Human Subjects  
FWA 0000165

MEMORANDUM

TO: Mary Mingels and John Graves
FROM: Mark Quinn, Chair
DATE: November 6, 2013

RE: “The Effects of Inquiry Activities in a Ninth Grade Physics” [MM110613-EX]

The above research, described in your submission of November 6, 2013, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

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

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

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

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

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

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

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

NEWTON’S 3RD LAW AND THE LAW OF CONSERVATION OF MOMENTUM
PRE-TEST
Newton's 3rd Law and the Law of Conservation of Momentum

Multiple Choice

Identify the letter of the choice that best completes the statement or answers the question.

1. The diagram below shows a ball tied to a string. A student is swinging the ball in a horizontal circle.

If the student releases the string, in which direction will the ball travel?

a. Direction W.  
   b. Direction X.  
   c. Direction Y.  
   d. Direction Z.

2. Which of the following is an example of increasing friction intentionally?

a. waxing skis  
   b. adding grease to gears on a bike  
   c. throwing sand on an icy driveway  
   d. oiling a squeaky door

3. According to the law of conservation of momentum, when two objects collide in the absence of friction,

   a. velocity decreases.  
   b. velocity increases.  
   c. momentum is not lost.  
   d. only the object with the larger mass continues on.

4. How can you increase the momentum of an object?

   a. by decreasing its velocity  
   b. by increasing its mass  
   c. by increasing its friction  
   d. by decreasing its acceleration

5. What is required for a rocket to lift off into space?

   a. thrust that is greater than Earth’s gravity  
   b. mass that is greater than Earth’s  
   c. very little air resistance  
   d. more velocity than friction

6. The product of an object’s mass and velocity is called its

   a. inertia.  
   b. momentum.  
   c. acceleration.  
   d. force.

7. Any force that causes an object to move in a circle is called a(n)

   a. balanced force.  
   b. unbalanced force.  
   c. gravitational force.  
   d. centripetal force.

8. An object that travels around another object in space is called a(n)

   a. projectile.  
   b. inertia.  
   c. mass.  
   d. satellite.

9. Forces can be added together only if they are

   a. acting on the same object.  
   b. unaffected by gravity.
10. Balanced forces acting on an object
   a. always change the object’s motion.
   b. sometimes change the object’s motion.
   c. never change the object’s motion.
   d. are not related to motion.

11. A student is driving her car when an insect strikes her windshield. Which of the following statements best describes the forces in this situation?
   a. The insect strikes the windshield with the same force as the windshield strikes the insect.
   b. The insect strikes the windshield with a force, and the windshield exerts no force on the insect.
   c. The insect exerts no force on the windshield, and the windshield strikes the insect with a large force.
   d. The insect strikes the windshield with a small force, and the windshield strikes the insect with a large force.

12. The diagram below shows a comet in an elliptical orbit around a star.

Which arrow indicates the direction of the gravitational force the star exerts on the comet when the comet is in the position shown?
   a. 1
   b. 2
   c. 3
   d. 4

13. According to Newton’s third law of motion, when a hammer strikes and exerts force on a nail, the nail
   a. creates a friction with the hammer.
   b. disappears into the wood.
   c. exerts an equal force back on the hammer.
   d. moves at a constant speed.

14. One way to increase acceleration is by
   a. increasing mass.
   b. decreasing mass.
   c. decreasing force.
   d. increasing both force and mass proportionally.

15. Which of the following is an example of exerting a force?
   a. a child running through a field
   b. a train speeding down a track
   c. a carpenter hammering a nail
   d. an airplane soaring through the sky

16. The momentum of an object is in the same direction as its
   a. force.
   b. acceleration.
   c. velocity.
   d. inertia.
17. A worker in a warehouse pushes two wooden boxes across a floor at a constant speed, as shown in the diagram below. The arrow in the diagram represents the force box 1 exerts on box 2. Which arrow represents the reaction force?

- a. 
- b. 
- c. 
- d. 

18. The moon accelerates because it is
- a. in a vacuum in space.
- b. continuously changing direction.
- c. a very large sphere.
- d. constantly increasing its speed of orbit.

19. The total momentum of a group of objects is conserved unless
- a. outside forces do not act on the objects.
- b. outside forces act on the objects.
- c. the objects are moving.
- d. there are more than two objects.

20. The achievement of lifting a rocket off the ground and into space can be explained by
- c. Newton’s third law.
- d. the law of conservation of momentum.

21. The greater the mass of an object,
- a. the easier the object starts moving.
- b. the greater its inertia.
- c. the more balanced it is.
- d. the more space it takes up.

22. A satellite in a circular orbit around Earth has a constant speed but not a constant velocity. Which of the following statements best explains why the satellite’s velocity is not constant?
- a. The radius of the satellite’s orbit is too large.
- b. The force on the satellite’s mass is constantly decreasing.
- c. The magnitude of the satellite’s momentum is too large.
- d. The direction of the satellite’s motion is constantly changing.

23. Which of the following has the greatest momentum?
- a. 0.2 kg ball moving at 40 m/s
- b. 500 kg car traveling at 26 m/s
- c. 2000 kg truck traveling at 5 m/s
- d. 50 kg child skateboarding at 4 m/s
APPENDIX C

NEWTON’S 3RD LAW AND THE LAW OF CONSERVATION OF MOMENTUM

POST-TEST
Newton's 3rd Law and the Law of Conservation of Momentum

Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question.

1. One way to increase acceleration is by
   a. increasing mass.  
   b. increasing both force and mass proportionally.  
   c. decreasing force.  
   d. decreasing mass.

2. According to the law of conservation of momentum, when two objects collide in the absence of friction,
   a. momentum is not lost.  
   b. velocity increases.  
   c. velocity decreases.  
   d. only the object with the larger mass continues on.

3. An object that travels around another object in space is called a(n)
   a. inertia.  
   b. mass.  
   c. projectile.  
   d. satellite.

4. The momentum of an object is in the same direction as its
   a. inertia.  
   b. acceleration.  
   c. velocity.  
   d. force.

5. Which of the following has the greatest momentum?
   a. 500 kg car traveling at 26 m/s  
   b. 0.2 kg ball moving at 40 m/s  
   c. 2000 kg truck traveling at 5 m/s  
   d. 50 kg child skateboarding at 4 m/s

6. How can you increase the momentum of an object?
   a. by increasing its mass  
   b. by increasing its friction  
   c. by decreasing its velocity  
   d. by decreasing its acceleration

7. The diagram below shows a ball tied to a string. A student is swinging the ball in a horizontal circle.

If the student releases the string, in which direction will the ball travel?
   a. Direction Z.  
   b. Direction W.  
   c. Direction X.  
   d. Direction Y.

8. Balanced forces acting on an object
   a. sometimes change the object’s motion.  
   b. never change the object’s motion.  
   c. always change the object’s motion.  
   d. are not related to motion.

9. The moon accelerates because it is
   a. continuously changing direction.  
   b. in a vacuum in space.  
   c. a very large sphere.  
   d. constantly increasing its speed of orbit.

10. The product of an object’s mass and velocity is called its
    a. force.  
    b. inertia.  
    c. momentum.  
    d. acceleration.

11. Which of the following is an example of increasing friction intentionally?
    a. throwing sand on an icy driveway  
    b. adding grease to gears on a bike
12. According to Newton’s third law of motion, when a hammer strikes and exerts force on a nail, the nail
   a. disappears into the wood.  
   b. creates a friction with the hammer.  
   c. moves at a constant speed.  
   d. exerts an equal force back on the hammer.

13. A worker in a warehouse pushes two wooden boxes across a floor at a constant speed, as shown in the diagram below.

The arrow in the diagram represents the force box 1 exerts on box 2. Which arrow represents the reaction force?
   a.  
   b.  
   c.  
   d.  

14. Forces can be added together only if they are
   a. balanced forces.  
   b. acting on the same object.  
   c. unaffected by gravity.  
   d. substantial.

15. The total momentum of a group of objects is conserved unless
   a. there are more than two objects.  
   b. the objects are moving.  
   c. outside forces act on the objects.  
   d. outside forces do not act on the objects.

16. Any force that causes an object to move in a circle is called a(n)
   a. centripetal force.  
   b. gravitational force.  
   c. balanced force.  
   d. unbalanced force.

17. A student is driving her car when an insect strikes her windshield. Which of the following statements best describes the forces in this situation?
   a. The insect strikes the windshield with a small force, and the windshield strikes the insect with a large force.
   b. The insect strikes the windshield with a force, and the windshield exerts no force on the insect.
   c. The insect exerts no force on the windshield, and the windshield strikes the insect with a large force.
   d. The insect strikes the windshield with the same force as the windshield strikes the insect.

18. The greater the mass of an object,
   a. the more balanced it is.  
   b. the greater its inertia.  
   c. the more space it takes up.  
   d. the easier the object starts moving.

19. What is required for a rocket to lift off into space?
   a. thrust that is greater than Earth’s gravity  
   b. mass that is greater than Earth’s gravity  
   c. mass that is greater than Earth’s gravity  
   d. the greater its inertia.
b. more velocity than friction
d. very little air resistance

20. A satellite in a circular orbit around Earth has a constant speed but not a constant velocity. Which of the following statements best explains why the satellite’s velocity is not constant?
   a. The radius of the satellite’s orbit is too large.
   b. The magnitude of the satellite’s momentum is too large.
   c. The force on the satellite’s mass is constantly decreasing.
   d. The direction of the satellite’s motion is constantly changing.

21. The diagram below shows a comet in an elliptical orbit around a star.

![Diagram of comet in orbit around a star]

Which arrow indicates the direction of the gravitational force the star exerts on the comet when the comet is in the position shown?
   a. 2  b. 1  c. 3  d. 4

22. Which of the following is an example of exerting a force?
   a. an airplane soaring through the sky
   b. a child running through a field
   c. a carpenter hammering a nail
   d. a train speeding down a track

23. The achievement of lifting a rocket off the ground and into space can be explained by
   a. the law of conservation of momentum.
   b. Newton’s second law.
   c. Newton’s third law.
   d. Newton’s first law.

Essay
24. What is the law of conservation of momentum? How can you show that the law is true for two objects that collide?

25. Kelly sits on a rock. Her weight is an action force. What is the reaction force?

26. People living at Earth’s equator are traveling at a speed of about 1,670 km/h as Earth spins on its axis. Are these people being accelerated? Explain.

27. A 2-kg cart slams into a stationary 2-kg cart at 4 m/s. The carts stick together and move forward at a speed of 2 m/s. Use the law of conservation of momentum to explain how the momentum was conserved.
28. Why don’t action-reaction forces cancel out?

29. An 8-kilogram ball moving at 10 m/sec to the right collides with a 4-kilogram ball at rest. After the collision, the 8-kilogram ball moves at 6 m/sec to the right. What is the velocity of the 4-kilogram ball? (Show your Work)

<table>
<thead>
<tr>
<th>Before 1</th>
<th>Before 2</th>
<th>Total Before</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 1</td>
<td>After 2</td>
<td>Total After</td>
</tr>
</tbody>
</table>

30. Projectile Motion 2: An arrow is shot straight forwards at 40m/s. It flies for 10s.
   a. Fill in the given information in the table below:

<table>
<thead>
<tr>
<th>Vertical</th>
<th>Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td>v₁=</td>
<td>v₁=</td>
</tr>
<tr>
<td>a=</td>
<td>a=</td>
</tr>
<tr>
<td>t=</td>
<td>t=</td>
</tr>
</tbody>
</table>

b. Find the final vertical velocity (Show work).

c. Find how far it falls down (Show Work).

d. Find how far it flies forwards (range) (show work)

31. Extra credit: A 0.10 kg hockey puck is at rest. It encounters a force of 20N for 0.2 seconds that sets it into motion. Over the next 2.0 Seconds, it encounters 0.4 N of resistance
force. Finally, it encounters a final force of 24 N for 0.05 seconds in the direction of motion. What is the final velocity of the hockey puck? (Show all work!)
APPENDIX D

WORK, POWER, AND ENERGY PRE-TEST
1. The scientist who suggested that energy can be created under certain conditions was
   a. Newton.  
   b. Einstein.  
   c. Wright.  
   d. Pascal.

2. The type of energy stored by fossil fuels such as coal is
   a. kinetic energy.  
   b. mechanical energy.  
   c. chemical potential energy.  
   d. electromagnetic energy.

3. Unlike kinetic energy, potential energy is
   a. energy of motion.  
   b. stored.  
   c. conserved.  
   d. not measurable.

4. What type of energy does a spinning turbine have?
   a. electrical energy  
   b. nuclear energy  
   c. thermal energy  
   d. mechanical energy

5. The rate at which energy is transferred is called
   a. joules.  
   b. power.  
   c. work.  
   d. time.

6. The energy associated with the motion and position of an object is
   a. kinetic energy.  
   b. potential energy.  
   c. gravitational potential energy.  
   d. mechanical energy.

7. Which of these is an example of work being done on an object?
   a. holding a heavy piece of wood at a construction site  
   b. trying to push a car that doesn’t move out of deep snow  
   c. pushing a child on a swing  
   d. holding a door shut on a windy day so it doesn’t blow open

8. Work is measured in
   a. meters.  
   b. pounds.  
   c. joules.  
   d. newtons.

9. In order to do work on an object, the force you exert must be
   a. the maximum amount of force you are able to exert.  
   b. in the same direction as the object’s motion.  
   c. in a direction opposite to Earth’s gravitational force.  
   d. quick and deliberate.

10. Energy is measured in units called
    a. joules.  
    b. pounds.  
    c. meters.  
    d. horsepower.

11. The energy associated with motion is called
    a. kinetic energy.  
    b. elastic potential energy.  
    c. gravitational potential energy.  
    d. nuclear energy.

12. Kinetic energy increases as
    a. mass increases and velocity decreases.  
    b. mass decreases and velocity increases.  
    c. both mass and velocity increase.  
    d. both mass and velocity decrease.

13. The total potential and kinetic energy of the particles in an object is called
    a. mechanical energy.  
    b. chemical energy.
b. thermal energy. d. electrical energy.

14. An example of something that stores chemical energy is
a. lightning. b. a microwave. c. a match. d. light.

15. When you rub your hands together on a cold day, you use friction to convert
a. mechanical energy into thermal energy. b. thermal energy into nuclear energy. c. nuclear energy into electrical energy. d. electrical energy into electromagnetic energy.

16. Energy stored in the nucleus of an atom is called
a. electromagnetic energy. c. mechanical energy. b. nuclear energy. d. chemical energy.

17. Visible light is an example of
a. chemical energy. c. electromagnetic energy. b. electrical energy. d. nuclear energy.

18. A waterfall is a good example of
a. kinetic energy being converted into potential energy. b. potential energy being converted into kinetic energy. c. energy being lost. d. energy being created.

19. The law of conservation of energy states that when one form of energy is converted into another,
 a. energy is destroyed in the process. b. no energy is destroyed in the process. c. energy is created in the process. d. some amount of energy cannot be accounted for.

20. How would you calculate an object’s mechanical energy?
 a. Add its kinetic and potential energies. b. Multiply its kinetic and potential energies. c. Subtract its kinetic energy from its potential energy. d. Subtract its potential energy from its kinetic energy.

21. A change from one form of energy into another is called
 a. gravitational potential energy. b. work. c. conservation of energy. d. an energy transformation.

22. If you exert a force of 20 newtons to push a desk 10 meters, how much work do you do on the desk?
 a. 200 joules b. 30 joules c. 10 joules d. 100 joules

23. Work equals force times
 a. energy. b. velocity. c. distance. d. mass.

24. Power is measured in units called
 a. joules. b. pounds. c. watts. d. newtons.
APPENDIX E

WORK, POWER, AND ENERGY POST-TEST
Work, Power, and Energy  
Multiple Choice  
Identify the letter of the choice that best completes the statement or answers the question.

1. The total potential and kinetic energy of the particles in an object is called  
   a. mechanical energy.  
   b. electrical energy.  
   c. thermal energy.  
   d. chemical energy.

2. What type of energy does a spinning turbine have?  
   a. mechanical energy  
   b. electrical energy  
   c. thermal energy  
   d. nuclear energy

3. An example of something that stores chemical energy is  
   a. a microwave.  
   b. lightning.  
   c. a match.  
   d. light.

4. Visible light is an example of  
   a. nuclear energy.  
   b. electromagnetic energy.  
   c. chemical energy.  
   d. electrical energy.

5. Energy is measured in units called  
   a. pounds.  
   b. horsepower.  
   c. joules.  
   d. meters.

6. The law of conservation of energy states that when one form of energy is converted into another,  
   a. energy is destroyed in the process.  
   b. no energy is destroyed in the process.  
   c. energy is created in the process.  
   d. some amount of energy cannot be accounted for.

7. The type of energy stored by fossil fuels such as coal is  
   a. electromagnetic energy.  
   b. chemical potential energy.  
   c. mechanical energy.  
   d. kinetic energy.

8. A waterfall is a good example of  
   a. kinetic energy being converted into potential energy.  
   b. energy being lost.  
   c. energy being created.  
   d. potential energy being converted into kinetic energy.

9. If you exert a force of 20 newtons to push a desk 10 meters, how much work do you do on the desk?  
   a. 10 joules  
   b. 100 joules  
   c. 200 joules  
   d. 30 joules

10. A change from one form of energy into another is called  
    a. conservation of energy.  
    b. work.  
    c. an energy transformation.  
    d. gravitational potential energy.

11. How would you calculate an object’s mechanical energy?  
    a. Multiply its kinetic and potential energies.  
    b. Subtract its kinetic energy from its potential energy.  
    c. Add its kinetic and potential energies.
d. Subtract its potential energy from its kinetic energy.

12. Which of these is an example of work being done on an object?
   a. holding a door shut on a windy day so it doesn’t blow open
   b. trying to push a car that doesn’t move out of deep snow
   c. holding a heavy piece of wood at a construction site
   d. pushing a child on a swing

13. The scientist who suggested that energy can be created under certain conditions was

14. Work equals force times
   a. energy.    b. velocity.  c. distance.  d. mass.

15. The energy associated with motion is called
   a. kinetic energy.      c. nuclear energy.
   b. elastic potential energy.  d. gravitational potential energy.

16. Unlike kinetic energy, potential energy is
   a. not measurable.    b. stored.  c. energy of motion.  d. conserved.

17. The energy associated with the motion and position of an object is
   a. mechanical energy.      c. potential energy.
   b. gravitational potential energy.  d. kinetic energy.

18. The rate at which energy is transferred is called
   a. work.    b. joules.    c. power.     d. time.

19. Energy stored in the nucleus of an atom is called
   a. mechanical energy.      c. nuclear energy.
   b. electromagnetic energy.  d. chemical energy.

20. Work is measured in
   a. newtons.    b. meters.    c. joules.   d. pounds.

21. Power is measured in units called
   a. pounds.    b. newtons.    c. watts.    d. joules.

22. When you rub your hands together on a cold day, you use friction to convert
   a. nuclear energy into electrical energy.
   b. electrical energy into electromagnetic energy.
   c. thermal energy into nuclear energy.
   d. mechanical energy into thermal energy.

23. In order to do work on an object, the force you exert must be
   a. in the same direction as the object’s motion.
   b. the maximum amount of force you are able to exert.
   c. in a direction opposite to Earth’s gravitational force.
   d. quick and deliberate.

24. Kinetic energy increases as
   a. both mass and velocity decrease.
   b. both mass and velocity increase.
   c. mass decreases and velocity increases.
   d. mass increases and velocity decreases.
SHOW ALL WORK for the following questions!

25. A 10 kg ball is rolling at 5 m/s, what type of energy does the ball have? How much does it have?

26. How much work is done to accelerate a 25 kg object at 10m/s² a distance of 10m?

27. A 50 kg rock is perched on the edge of a cliff 100m high. What type of energy does the rock have? How much does it have?

Short Answer

Use the diagram to answer each question.

28. Compare the speed of the basketball at positions A and D. Explain your comparison.

29. Which letter represents the position at which the basketball has the least potential energy? Explain.
30. Which letter represents the position at which the basketball has the greatest kinetic energy? Explain.

31. Describe two energy conversions that take place when you warm a cup of cocoa in a microwave oven.

32. A 70 kg person is swinging on a swing set, as shown in the diagram below. Positions X and Z represent the highest points of the person’s motion, and position Y represents the lowest point of the person’s motion.

![Swing Set Diagram]

a) At which position does the person have maximum kinetic energy? Explain your answer.

b) Neglecting friction, describe the energy conversion as the person travels from position X to position Y.

c) The person is 1.0 m above the ground at position Y and 1.5 m above the ground at position Z. Neglecting friction, calculate the change in gravitational potential energy as the person swings from position Y to position Z. Show your calculations and include units in your answer.

d) Neglecting friction, calculate the speed of the person at position Y. Show your calculations and include units in your answer.
APPENDIX F

HEAT AND HEAT TRANSFER PRE-TEST
Heat and Heat Transfer

Multiple Choice

Identify the letter of the choice that best completes the statement or answers the question.

____ 1. No more energy can be removed from matter at
   a. its freezing point.  b. 0°C.  c. absolute zero.  d. 273 K.

____ 2. The total energy of all the particles in a substance is called
   a. temperature.  b. thermal energy.  c. degrees.  d. mass.

____ 3. The more particles a substance has at a given temperature,
   a. the higher its temperature.  b. the more thermal energy it has.
   c. the more degrees it has.  d. the more kelvins it has.

____ 4. The movement of thermal energy from a warmer object to a cooler object is called
   a. heat.  b. temperature.  c. motion.  d. momentum.

____ 5. Heat, like work, is an energy transfer measured in
   a. watts.  b. degrees.  c. joules.  d. kelvins.

____ 6. Heat is transferred from one particle of matter to another without the movement of matter itself in a process called
   a. conduction.  b. convection.  c. radiation.  d. insulation.

____ 7. The transfer of energy by electromagnetic waves is called
   a. conduction.  b. convection.  c. radiation.  d. insulation.

____ 8. Heat transfer occurs
   a. in many directions.
   b. both from warm objects to colder ones and from cold objects to warmer ones.
   c. only from warm objects to colder ones.
   d. only from cold objects to warmer ones.

____ 9. A material that does NOT conduct heat well is called a(n)
   a. insulator.  b. conductor.  c. metal.  d. radiator.

____ 10. The amount of energy required to raise the temperature of 1 kilogram of a substance by 1 kelvin is called its
    a. specific heat.  b. heat transfer.  c. change of state.  d. melting point.

____ 11. How many different forms, or states, does most matter on Earth exist in?
    a. one  b. two  c. three  d. fifty

____ 12. The addition or loss of thermal energy changes the arrangement of the particles during
    a. a change of state.  b. conduction.  c. convection.  d. radiation.

____ 13. The temperature at which a solid changes into a liquid is called
    a. the boiling point.  b. the freezing point.  c. the melting point.  d. absolute zero.

____ 14. Vaporization that takes place only at the surface of a liquid is called
    a. melting.  b. boiling.  c. evaporation.  d. condensation.

____ 15. The expanding of matter when it is heated is known as
    a. condensation.  b. evaporation.  c. thermal expansion.  d. vaporization.

____ 16. One common application of thermal expansion is
    a. a toaster oven.  b. a microwave oven.  c. a refrigerator.  d. a thermostat.
17. Absolute zero is shown as 0 on which scale?
   a. Fahrenheit  b. Celsius  c. Kelvin  d. Centigrade

18. Which of the following is true of the Celsius scale?
   a. 212 degrees is the boiling point of water.
   b. 0 degrees is absolute zero.
   c. 0 degrees is the freezing point of water.
   d. 32 degrees is the freezing point of water.

19. Heated air moves from baseboard heaters to the rest of a room in a process called
   a. conduction.  b. convection.  c. radiation.  d. insulation.

20. Which statement is true of gases?
   a. The particles that make up gases are packed together in a relatively fixed position.
   b. Gases have a definite volume.
   c. Gases have a definite shape.
   d. Gases expand to fill all the space available.

21. A measure of the average kinetic energy of the individual particles in an object is called
   a. thermal energy.  b. conduction.  c. convection.  d. temperature.

22. If 100 grams of hot water at 50°C is mixed with 100 grams of cold water at 15°C, what will the equilibrium temperature be?
   a. 26.6°C  b. 32.5°C  c. 38.3°C  d. 75.0°C

23. The masses and specific heats of some samples of liquids are shown in the table below.
   The temperature of which sample will rise most when 1000 J of heat is added?

<table>
<thead>
<tr>
<th>Samples</th>
<th>Mass (kg)</th>
<th>Specific Heat Capacity (J/kg • K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>0.750</td>
<td>4200</td>
</tr>
<tr>
<td>glycerin</td>
<td>0.750</td>
<td>2400</td>
</tr>
<tr>
<td>methanol</td>
<td>0.750</td>
<td>2500</td>
</tr>
<tr>
<td>cooking oil</td>
<td>0.750</td>
<td>2100</td>
</tr>
</tbody>
</table>


24. A recycling plant manager needs to melt 1500 kg scrap copper to sell to a wire manufacturer. The copper is at 15°C and its melting point is 1083°C. The copper has a specific heat of 385 J/kg • K. How much heat is required to raise the temperature of the copper to its melting point?
   a. $6.2 \times 10^8$ J  b. $6.3 \times 10^8$ J  c. $7.7 \times 10^8$ J  d. $7.9 \times 10^8$ J

25. A student slowly heats a beaker of a liquid on a hot plate. The liquid has a boiling point of 78°C. The student makes the graph shown below from the data she records as the liquid is heating. Which of the following statements best describes what happens to the molecules of liquid between 5 and 10 minutes of heating?
a. The mass of the molecules increases.  
b. The molecules undergo a chemical change.  
c. The molecules absorb energy to change phase.  
d. The average kinetic energy of the molecules decreases.
APPENDIX G

HEAT AND HEAT TRANSFER POST-TEST
Heat and Heat Transfer

Multiple Choice

Identify the letter of the choice that best completes the statement or answers the question.

___ 1. Which statement is true of gases?
   a. Gases expand to fill all the space available.
   b. The particles that make up gases are packed together in a relatively fixed position.
   c. Gases have a definite shape.
   d. Gases have a definite volume.

___ 2. The addition or loss of thermal energy changes the arrangement of the particles during
   a. radiation.
   b. a change of state.
   c. convection.
   d. conduction.

___ 3. No more energy can be removed from matter at
   a. 273 K.
   b. its freezing point.
   c. 0°C.
   d. absolute zero.

___ 4. Heat is transferred from one particle of matter to another without the movement of matter
   itself in a process called
   a. conduction.
   b. radiation.
   c. convection.
   d. insulation.

___ 5. Heat, like work, is an energy transfer measured in
   a. watts.
   b. joules.
   c. kelvins.
   d. degrees.

___ 6. The total energy of all the particles in a substance is called
   a. temperature.
   b. mass.
   c. degrees.
   d. thermal energy.

___ 7. If 100 grams of hot water at 50°C is mixed with 100 grams of cold water at 15°C, what will the equilibrium temperature be?
   a. 32.5°C
   b. 26.6°C
   c. 75.0°C
   d. 38.3°C

___ 8. The expanding of matter when it is heated is known as
   a. evaporation.
   b. condensation.
   c. thermal expansion.
   d. vaporization.

___ 9. A measure of the average kinetic energy of the individual particles in an object is called
   a. conduction.
   b. temperature.
   c. thermal energy.
   d. convection.

___ 10. Absolute zero is shown as 0 on which scale?
    a. Centigrade
    b. Fahrenheit
    c. Celsius
    d. Kelvin

___ 11. The transfer of energy by electromagnetic waves is called
    a. insulation.
    b. conduction.
    c. convection.
    d. radiation.

___ 12. One common application of thermal expansion is
    a. a toaster oven.
    b. a refrigerator.
    c. a thermostat.
    d. a microwave oven.

___ 13. Heat transfer occurs
    a. both from warm objects to colder ones and from cold objects to warmer ones.
    b. only from cold objects to warmer ones.
    c. in many directions.
    d. only from warm objects to colder ones.

___ 14. A recycling plant manager needs to melt 1500 kg scrap copper to sell to a wire
    manufacturer. The copper is at 15°C and its melting point is 1083°C. The copper has a
    specific heat of 385 J/kg • K. How much heat is required to raise the temperature of the
    copper to its melting point?
    a. $7.9 \times 10^8$ J
    b. $6.3 \times 10^8$ J
    c. $6.2 \times 10^8$ J
    d. $7.7 \times 10^8$ J
15. A material that does NOT conduct heat well is called a(n)
   a. conductor.  b. insulator.  c. metal.  d. radiator.

16. How many different forms, or states, does most matter on Earth exist in?
   a. fifty  b. one  c. two  d. three

17. The masses and specific heats of some samples of liquids are shown in the table below.
    The temperature of which sample will rise most when 1000J of heat is added?

    | Samples     | Mass (kg) | Specific Heat Capacity (J/kg • K) |
    |-------------|-----------|-----------------------------------|
    | water       | 0.750     | 4200                              |
    | glycerin    | 0.750     | 2400                              |
    | methanol    | 0.750     | 2500                              |
    | cooking oil | 0.750     | 2100                              |


18. A student slowly heats a beaker of a liquid on a hot plate. The liquid has a boiling point of 78°C. The student makes the graph shown below from the data she records as the liquid is heating. Which of the following statements best describes what happens to the molecules of liquid between 5 and 10 minutes of heating?
   a. The mass of the molecules increases.
   b. The molecules undergo a chemical change.
   c. The molecules absorb energy to change phase.
   d. The average kinetic energy of the molecules decreases.

19. The amount of energy required to raise the temperature of 1 kilogram of a substance by 1 kelvin is called its
   a. heat transfer.  b. change of state.  c. melting point.  d. specific heat.

20. The more particles a substance has at a given temperature,
   a. the more kelvins it has.  b. the higher its temperature.
   c. the more degrees it has.  d. the more thermal energy it has.

21. The movement of thermal energy from a warmer object to a cooler object is called
   a. motion.  b. momentum.  c. temperature.  d. heat.

22. Heated air moves from baseboard heaters to the rest of a room in a process called
   a. convection.  b. conduction.  c. radiation.  d. insulation.

23. Vaporization that takes place only at the surface of a liquid is called
a. melting. b. boiling. c. evaporation. d. condensation.

23. Which of the following is true of the Celsius scale?
   a. 32 degrees is the freezing point of water. c. 0 degrees is absolute zero.
   b. 0 degrees is the freezing point of water. d. 212 degrees is the boiling point of water.

25. The temperature at which a solid changes into a liquid is called
   a. the boiling point. b. the melting point. c. the freezing point. d. absolute zero.

**Short Answer**

*Use the diagram to answer each question.*

26. Label the states of matter and phase changes of a pure substance that are represented in the graph.

**Essay**

27. Describe how a thermometer works.

28. What is the difference between thermal energy and heat?
29. Why does heat flow from hot to cold?

30. A student heats a 200 g sample of water from 20°C to 80°C. The specific heat of water is 4.18 J/g • °C.
   a) Calculate the thermal energy absorbed by the water. Show your calculations and include units in your answer.

   The student then boils the water.
   b) Describe what happens to the temperature of the water as it boils. Explain your answer.

   The student repeats the experiment, this time placing a small block of iron into another 200 g sample of water. The specific heat of iron is 0.45 J/g • °C. Both the iron and the water are initially at 20°C and are heated to 80°C.

   c) Compare the amount of thermal energy absorbed by the water in this experiment with your calculation in part (a). Explain your answer.

   d) Describe how repeating the second experiment with a block made of a material with a greater specific heat will affect the amount of time it takes to heat the block. Assume the blocks have the same mass.

31. Explain what Sea Breezes and Land Breezes are and how/why/when Sea Breezes and Land Breezes occur (EXTRA CREDIT!)
APPENDIX H

FORMATIVE ASSESSMENTS AND QUIZZES
SAMPLE FORMATIVE ASSESSMENTS

This was given using the website m.socrative.com:

1. Name
2. How well did you understand the material (multiple choice)?
3. What did you learn today (free response)?
4. Please solve the problem on the board (free response)?

Activator and Summarizer questions were also used based on the day’s lessons.
Quiz: Projectiles, 3\textsuperscript{rd} Law, and Momentum

1) Projectile Motion: An arrow is shot straight up at 60m/s. It is in the air for 12s.
   a. What is the vertical acceleration?
   b. How fast will it go when it lands?
   c. How high will it go up in the air (Note, only use half of the time because that is when it will reach its peak!)

2) Projectile Motion 2: An arrow is shot straight forwards at 75m/s. It flies for 15s.
   a. Fill in the given information in the table below:
      | Vertical | Horizontal |
      | $v_1=$ | $v_1=$ |
      | $a=$ | $a=$ |
      | $t=$ | $t=$ |

3) How does a walking employ Newton’s 3\textsuperscript{rd} Law of motion?

4) Which of the following pairs are action-reaction pairs? (circle all that apply)
   A. The sun shines and the snow melts
   B. The ball hits the window and the window breaks
   C. Jenna pushes on the table and the table pushes on Jenna

5) What 2 pieces of information do we need to know in order to calculate the momentum for the object? Include the units for each!

6) Which of the following has the greatest momentum? (Show your work for each, then circle the one that’s the greatest)
   A. 0.2 kg ball moving at 40 m/s  $m=$ $v=$ $p=$
   B. 500 kg car traveling at 16 m/s  $m=$ $v=$ $p=$
   C. 2000 kg truck traveling at 9 m/s  $m=$ $v=$ $p=$
D. 50 kg child skateboarding at 4 m/s  \( m = \quad v = \quad p = \)

7) An 18 kg cart is traveling at a velocity of 2 m/s. The cart collides with a stationary 12 kg toy car. After the collision, the two objects stick together and continue moving in the same direction. What is the final \textbf{velocity} of the two objects?

<table>
<thead>
<tr>
<th>Cart Before</th>
<th>Toy Car Before</th>
<th>Total Before</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>
Chapter 4 Section 1 Quiz

1. Formula for work: (in both words and letter symbols)

2. Formula for power: (both in words and letter symbols)

3. Work formula to solve for Distance. (d=)

4. His sofa is stuck! Is work being done on the sofa? Explain how you got your answer.

___________________________________________________________
___________________________________________________________
___________________________________________________________
___________________________________________________________
___________________________________________________________
5. Is work being done on the wagon? Explain how you know the answer.

6. Solve this problem: How much work is done by a person who uses a force of 15N to move a grocery buggy 3m?

7. Solve this problem: A motor exerts a force of 50,000 N to lift an elevator 20.0 m in 5.0 seconds. What is the power of the motor?

8. A machine uses 50 Newtons of force to move an object. If the machine uses 350 Watts in 7 seconds, how much work does the machine do? And how far is the object moved?
Temperature Quiz – Show all work!

°C = \frac{5}{9}(°F - 32)
°F = \left(\frac{9}{5}•°C\right) + 32
K = °C + 273
°C = K - 273
Q = mc\Delta T

°C = Degrees Celsius
°F = Degrees Fahrenheit
K = Kelvin
Q = Thermal (Heat) Energy
m = mass
c = specific heat
\Delta T = Change in temperature = (T_2 - T_1)

1) This morning it was 35°F, but your friend from Germany things that means its really warm! What is the temperature in degrees Celsius that you should tell your friend so they understand that this is actually pretty cold?

2) Your grandmother sends you a cookie recipe that says to bake the cookies at about 175°C, what temperature, in degrees Fahrenheit, would you set your oven to?

3) A gas has a boiling point of -200°C, what is this in Kelvin?

4) What is absolute zero in Kelvin? Degrees Celsius? Degrees Fahrenheit?

5) Oil has a specific heat of 1900J/kg°C, while aluminum has a specific heat of 900J/kg°C. If you have 5 kg of each, which will require more energy to be heated up 10°C?
Physics Understanding and Engagement Survey – Pre-treatment

Participation in this research survey is voluntary and participation or non-participation will not affect a student’s grades or class standing in any way.

Your responses will be kept confidential and any use of them will be done so anonymously. Your name will not appear in any record of this study, nor will it appear in any publication of the results.

Using the following scale, please indicate how you feel about each statement.

1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

1. I like the typical class structure we have used since the beginning of the year (Pre-test, Reading in book, Direct Instruction/Taking Notes, Follow-up Activity).
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

2. I feel like I learn a lot from the typical class structure.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

3. I feel engaged during the lectures/note taking times.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

4. Throughout the unit I understand what is being taught.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

5. At the end of the unit, I have learned a lot.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

6. When I have questions, they are answered pretty quickly.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

7. I am often bored during class.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

8. The tests are easy at the end of the unit.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

9. I would prefer to do more lab activities.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

10. When working in groups in class, I participate with my group.
1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

11. I learn more from lectures/taking notes than I do from reading the book.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

12. I learn more from working in groups than I do from lectures/taking notes.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

13. I like Physics Class.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

14. I feel prepared to answer questions on this information this Spring on the MCAS Physics Exam.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

15. When I don’t understand something, I come afterschool for extra help.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

16. When I don’t understand something, I look online or in my book for more information.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

17. How has the way concepts are taught in class affected your learning in this class?

18. Do you have any suggestions for improving class?

19. Is there anything else you’d like me to know?
Physics Understanding and Engagement Survey – After Inquiry First Treatment

Participation in this research survey is voluntary and participation or non-participation will not affect a student’s grades or class standing in any way.

Your responses will be kept confidential and any use of them will be done so anonymously. Your name will not appear in any record of this study, nor will it appear in any publication of the results.

Using the following scale, please indicate how you feel about each statement.

1-Agree Completely  2-Somewhat Agree  3-Neutral  4-Somewhat Disagree  5-Strongly Disagree

1. I liked starting with an inquiry activity first better than the typical class structure we used at the start of the year (Pre-test, Reading in book, Direct Instruction/Taking Notes, Follow-up Activity).
   1-Agree Completely  2-Somewhat Agree  3-Neutral  4-Somewhat Disagree  5-Strongly Disagree

2. I feel like I learned a lot from the inquiry activity.
   1-Agree Completely  2-Somewhat Agree  3-Neutral  4-Somewhat Disagree  5-Strongly Disagree

3. I felt more engaged during the lectures/note taking times because of the inquiry activity.
   1-Agree Completely  2-Somewhat Agree  3-Neutral  4-Somewhat Disagree  5-Strongly Disagree

4. Throughout the unit I understood what was being taught.
   1-Agree Completely  2-Somewhat Agree  3-Neutral  4-Somewhat Disagree  5-Strongly Disagree

5. At the end of the unit, I had learned a lot.
   1-Agree Completely  2-Somewhat Agree  3-Neutral  4-Somewhat Disagree  5-Strongly Disagree

6. When I had questions, they were answered pretty quickly.
   1-Agree Completely  2-Somewhat Agree  3-Neutral  4-Somewhat Disagree  5-Strongly Disagree

7. I felt confused during the inquiry activity.
   1-Agree Completely  2-Somewhat Agree  3-Neutral  4-Somewhat Disagree  5-Strongly Disagree

8. I was often bored during class.
   1-Agree Completely  2-Somewhat Agree  3-Neutral  4-Somewhat Disagree  5-Strongly Disagree

9. The test was easy at the end of the unit.
   1-Agree Completely  2-Somewhat Agree  3-Neutral  4-Somewhat Disagree  5-Strongly Disagree

10. I felt frustrated during the inquiry activity.
11. I would prefer to do more of the inquiry activities.

12. When working in groups in class, I participate with my group.

13. I felt bored during the inquiry activity.


15. I learn more from lectures/taking notes than I do from reading the book.

16. I learn more from working in groups than I do from lectures/taking notes.

17. I like Physics Class.

18. I feel prepared to answer questions on this information this Spring on the MCAS Physics Exam.

19. When I don’t understand something, I come afterschool for extra help.

20. When I don’t understand something, I look online or in my book for more information.

21. I liked the inquiry activities better than the standard lab activities we did before?

22. How has the way concepts were taught in class affected your learning in this class?

23. Do you have any suggestions for improving class?
24. Is there anything else you’d like me to know?

Physics Understanding and Engagement Survey – After Instruction First Treatment

Participation in this research survey is voluntary and participation or non-participation will not affect a student’s grades or class standing in any way.

Your responses will be kept confidential and any use of them will be done so anonymously. Your name will not appear in any record of this study, nor will it appear in any publication of the results.

Using the following scale, please indicate how you feel about each statement.

1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

1. I liked starting with instruction followed by an inquiry activity better than the typical class structure we used at the start of the year (Pre-test, Reading in book, Direct Instruction/Taking Notes, Follow-up Activity).
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

2. I feel like I learned a lot from the inquiry activity.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

3. I felt more engaged during the lectures/note taking times because of the inquiry activity.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

4. Throughout the unit I understood what was being taught.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

5. At the end of the unit, I had learned a lot.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

6. When I had questions, they were answered pretty quickly.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

7. I was often bored during class.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

8. The test was easy at the end of the unit.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree
9. I would prefer to do more of the inquiry activities.
   1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

10. When working in groups in class, I participate with my group.
    1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

11. I learn more from lectures/taking notes than I do from reading the book.
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12. I felt confused during the inquiry activity.
    1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

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    1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

    1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

15. I felt frustrated during the inquiry activity.
    1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

16. I learn more from working in groups than I do from lectures/taking notes.
    1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

17. I like Physics Class.
    1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

18. I feel prepared to answer questions on this information this Spring on the MCAS Physics Exam.
    1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

19. When I don’t understand something, I come afterschool for extra help.
    1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

20. When I don’t understand something, I look online or in my book for more information.
    1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree

21. I liked the inquiry activities better than the standard lab activities we did before?
    1-Agree Completely   2-Somewhat Agree   3-Neutral   4-Somewhat Disagree   5-Strongly Disagree
22. How has the way concepts were taught in class affected your learning in this class?

23. Do you have any suggestions for improving class?

24. Is there anything else you’d like me to know?
APPENDIX J
2013 INTRODUCTORY PHYSICS MCAS EXAM
High School Introductory Physics Test


The Science and Technology/Engineering Curriculum Framework is available on the Department website at www.doe.mass.edu/frameworks/current.html.

Introductory Physics test results are reported under the following four MCAS reporting categories:

- Motion and Forces
- Heat and Heat Transfer
- Waves and Radiation
- Electromagnetism

Test Sessions

The high school Introductory Physics test included two separate test sessions, which were administered on consecutive days. Each session included multiple-choice and open-response questions.

Reference Materials and Tools

Each student taking the high school Introductory Physics test was provided with an Introductory Physics Formula Sheet. A copy of this formula sheet follows the final question in this chapter.

Each student also had sole access to a calculator with at least four functions and a square-root key.

The use of bilingual word-to-word dictionaries was allowed for current and former English language learner students only, during both Introductory Physics test sessions. No other reference tools or materials were allowed.

Cross-Reference Information

The table at the conclusion of this chapter indicates each item’s reporting category and the framework learning standard it assesses. The correct answers for multiple-choice questions are also displayed in the table.
Introductory Physics

SESSION 1

DIRECTIONS
This session contains twenty-one multiple-choice questions and two open-response questions. Mark your answers to these questions in the spaces provided in your Student Answer Booklet. You may work out solutions to multiple-choice questions in the test booklet.

1. A rope is attached to a block that has a weight of 120 N. When the rope exerts an upward force of 250 N on the block, what is the net force on the block?
   A. 130 N up
   B. 370 N up
   C. 130 N down
   D. 370 N down

2. A student is shaking one end of a small rug with a ball on top of it. The wave that is produced travels through the rug and moves the ball upward, as shown in the diagram below.

Which type of wave is produced in the rug?
   A. compression
   B. electromagnetic
   C. longitudinal
   D. transverse
3. A student has a circuit that is missing a component at location X, as shown in the diagram below.

The student wants component Y to warm up after the switch is closed. Which of the following components should the student add to the circuit at location X?

A. 

B. 

C. 

D. 

4. A satellite in a circular orbit around Earth has a constant speed but not a constant velocity. Which of the following statements best explains why the satellite’s velocity is not constant?

A. The radius of the satellite’s orbit is too large.
B. The force on the satellite’s mass is constantly decreasing.
C. The magnitude of the satellite’s momentum is too large.
D. The direction of the satellite’s motion is constantly changing.
5. An object is traveling in a straight line. The graph below shows the object’s velocity over time.

Motion of an Object

Which line segment shows the object traveling with a constant, positive acceleration?

- A. segment W
- B. segment X
- C. segment Y
- D. segment Z

6. A person is driving north in a car at a constant speed. A police officer is driving south toward him at a constant speed. The police officer uses a radar unit to measure the speed of the person’s car. The radar unit sends out waves of a certain frequency toward the person’s car. The waves reflect off the person’s car and travel back to the radar unit in the police car.

What happens to the frequency of the waves detected by the radar unit?

- A. The frequency is lower as the person’s car approaches.
- B. The frequency is higher as the person’s car approaches.
- C. The frequency remains the same but with increased energy as the person’s car approaches.
- D. The frequency remains the same but with decreased energy as the person’s car approaches.
A student slowly heats a beaker of a liquid on a hot plate. The liquid has a boiling point of 78°C. The student makes the graph shown below from the data she records as the liquid is heating.

**Heating a Liquid**

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
</tr>
</tbody>
</table>

Which of the following statements best describes what happens to the molecules of liquid between 5 and 10 minutes of heating?

A. The mass of the molecules increases.
B. The molecules undergo a chemical change.
C. The molecules absorb energy to change phase.
D. The average kinetic energy of the molecules decreases.

Which of the following statements describes an electric generator?

A. A magnet is rotated through a coil of wire to produce an electric current.
B. Electric potential in a rotating coil of wire creates a permanent magnet.
C. An electrical current causes a coil of wire to rotate in a magnetic field.
D. Forces from a permanent magnet allow a coil of wire to rotate.

A neutral balloon is rubbed with a piece of wool cloth. As a result, the balloon has a negative static charge.

Which of the following statements best explains why the balloon has a negative charge?

A. The balloon is a conductor.
B. The balloon is an insulator.
C. The balloon transfers charges to the cloth.
D. The balloon receives charges from the cloth.
10. What is the magnitude of the momentum of a 0.50 kg ball moving in a straight line at 5.0 m/s?
   A. 0.1 kg \cdot m/s
   B. 2.5 kg \cdot m/s
   C. 6.3 kg \cdot m/s
   D. 10 kg \cdot m/s

11. The human ear is most sensitive to sound that has a frequency of about 4000 Hz. Assume that the speed of sound in air is 340 m/s.
   What is the wavelength of a sound heard in the air with this frequency?
   A. 0.043 m
   B. 0.085 m
   C. 12 m
   D. 340 m
Question 12 is an open-response question.

- BE SURE TO ANSWER AND LABEL ALL PARTS OF THE QUESTION.
- Show all your work (diagrams, tables, or computations) in your Student Answer Booklet.
- If you do the work in your head, explain in writing how you did the work.

Write your answer to question 12 in the space provided in your Student Answer Booklet.

12 A student performs an experiment to determine the relationships among voltage, current, and resistance. The student’s procedure includes the following steps:

- Connect a 3.0 V battery to a 42 Ω resistor.
- Measure the current using an ammeter and record the value.
- Replace the 42 Ω resistor with a 54 Ω resistor, and then with a 66 Ω resistor, measuring and recording the current for each resistor.

The table below shows the data collected.

**Student’s Data**

<table>
<thead>
<tr>
<th>Resistance (Ω)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>0.071</td>
</tr>
<tr>
<td>54</td>
<td>0.056</td>
</tr>
<tr>
<td>66</td>
<td>0.045</td>
</tr>
</tbody>
</table>

a. In your Student Answer Booklet, draw a schematic diagram of the student’s original circuit with the 42 Ω resistor. Be sure to label the battery and the resistor.

b. Describe in words the relationship between current and resistance as voltage is held constant.

The student will investigate these relationships further using a different experiment.

c. Write a procedure the student could use to test the relationships among voltage, current, and resistance if the only materials available for use are three 3.0 V batteries, one 30 Ω resistor, wire, and an ammeter.

d. In your Student Answer Booklet, make a data table similar to the Student’s Data table above to show the expected current measurements for your procedure from part (c). Show your calculations and include units in your answer.
Mark your answers to multiple-choice questions 13 through 22 in the spaces provided in your Student Answer Booklet. Do not write your answers in this test booklet, but you may work out solutions to multiple-choice questions in the test booklet.

13 A light bulb with a potential difference of 120 V across it carries a current of 1.5 A. Which of the following is the power consumption of the light bulb?
A. 0.013 W  
B. 80 W  
C. 120 W  
D. 180 W

14 Electromagnetic waves with low frequencies have been used for long-distance underwater communication. These waves most likely belong to which of the following parts of the electromagnetic spectrum?
A. gamma rays  
B. infrared waves  
C. radio waves  
D. x-rays

15 An electric fan has a power output of 60 W. How much work is done if the fan operates for 120 s?
A. 0.5 J  
B. 60 J  
C. 120 J  
D. 7200 J

16 The diagram below represents a block sliding across a table at a constant speed. All forces are shown except the frictional force.

What is the magnitude of the frictional force on the block?
A. 0.8 N  
B. 1.6 N  
C. 1.7 N  
D. 2.5 N

17 During a thunderstorm, which of the following travels at a speed closest to $3.00 \times 10^8$ m/s?
A. wind from the storm  
B. sound from the thunder  
C. light from the lightning  
D. rain from the storm clouds
18. An athlete is training for a race by performing timed trials of sprints up a staircase. Which set of variables most directly affects the athlete’s power?

A. body weight, height climbed, width of steps
B. body weight, time spent climbing, width of steps
C. height climbed, time spent climbing, body weight
D. height climbed, time spent climbing, width of steps

20. Which of the following statements best explains how heat flows by conduction?

A. A large mass of air begins to move faster.
B. Energy is transferred by electromagnetic waves.
C. Energy is transferred from molecule to molecule.
D. A large mass of warm air rises, replacing the cooler air above.

19. An appliance draws 4 A of current when connected to 120 V. What is the resistance of the appliance?

A. 0.03 Ω
B. 30 Ω
C. 124 Ω
D. 480 Ω
21. Which of the following graphs best represents how the force between two identical electric charges varies as the charges move away from each other?

A.  

```
<table>
<thead>
<tr>
<th>Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m)</td>
</tr>
</tbody>
</table>
```

B.  

```
<table>
<thead>
<tr>
<th>Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m)</td>
</tr>
</tbody>
</table>
```

C.  

```
<table>
<thead>
<tr>
<th>Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m)</td>
</tr>
</tbody>
</table>
```

D.  

```
<table>
<thead>
<tr>
<th>Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m)</td>
</tr>
</tbody>
</table>
```

22. Which of the following properties makes a light wave different from all mechanical waves?

A. A light wave slows down in a vacuum.
B. A light wave is able to transmit energy.
C. A light wave exists as a transverse wave.
D. A light wave can travel without a medium.
Question 23 is an open-response question.

- **BE SURE TO ANSWER AND LABEL ALL PARTS OF THE QUESTION.**
- Show all your work (diagrams, tables, or computations) in your Student Answer Booklet.
- If you do the work in your head, explain in writing how you did the work.

Write your answer to question 23 in the space provided in your Student Answer Booklet.

23 A 70 kg person is swinging on a swing set, as shown in the diagram below. Positions X and Z represent the highest points of the person’s motion, and position Y represents the lowest point of the person’s motion.

![Diagram of a swing set with positions X, Y, and Z labeled.]

a. At which position does the person have maximum kinetic energy? Explain your answer.

b. Neglecting friction, describe the energy conversion as the person travels from position X to position Y.

c. The person is 1.0 m above the ground at position Y and 1.5 m above the ground at position Z. Neglecting friction, calculate the change in gravitational potential energy as the person swings from position Y to position Z. Show your calculations and include units in your answer.

d. Neglecting friction, calculate the speed of the person at position Y. Show your calculations and include units in your answer.
**Introductory Physics**  
**SESSION 2**

**DIRECTIONS**  
This session contains nineteen multiple-choice questions and three open-response questions. Mark your answers to these questions in the spaces provided in your Student Answer Booklet. You may work out solutions to multiple-choice questions in the test booklet.

24. The graph below represents the motion of an object over four time intervals, W, X, Y, and Z.

![Motion of an Object](image)

Over which time interval is the object moving the fastest?

A. interval W  
B. interval X  
C. interval Y  
D. interval Z

25. Which of the following observed properties of a wave is changed by the Doppler effect?

A. amplitude  
B. direction  
C. frequency  
D. speed

26. A person starts driving and travels 3 km east to a store. The person then turns around and travels 1 km west to another store. Finally, the person travels 2 km west, back to the starting point.

What distance has this person traveled?

A. 0 km  
B. 3 km  
C. 5 km  
D. 6 km

27. A 2 m long pendulum swings back and forth 6 times in 17 seconds. What is the period of the pendulum?

A. 0.4 s  
B. 2.8 s  
C. 12 s  
D. 34 s
28 The diagram below shows two students making a wave with a coiled spring.

Which of the following waves move most like the wave in the coiled spring?

A. infrared waves  
B. microwaves  
C. sound waves  
D. ultraviolet waves

29 A student researches Jupiter and Saturn and records the following information:

- Jupiter is about half the distance to the Sun that Saturn is.
- Jupiter is about three times more massive than Saturn.

Based on this information, which of the following can be concluded about the gravitational forces between these planets and the Sun?

A. There are no gravitational forces between Jupiter and the Sun or between Saturn and the Sun.

B. There are equal gravitational forces between Saturn and the Sun and between Jupiter and the Sun.

C. There is a greater gravitational force between Jupiter and the Sun than between Saturn and the Sun.

D. There is a greater gravitational force between Saturn and the Sun than between Jupiter and the Sun.
30. Which of the following substances has the lowest average molecular kinetic energy?
   A. nitrogen at 75°C
   B. quartz at 25°C
   C. steel at 50°C
   D. water at 10°C

31. The diagram below shows a ball tied to a string. A student is swinging the ball in a horizontal circle.

If the student releases the string, in which direction will the ball travel?
   A. direction W
   B. direction X
   C. direction Y
   D. direction Z
Question 32 is an open-response question.

- BE SURE TO ANSWER AND LABEL ALL PARTS OF THE QUESTION.
- Show all your work (diagrams, tables, or computations) in your Student Answer Booklet.
- If you do the work in your head, explain in writing how you did the work.

Write your answer to question 32 in the space provided in your Student Answer Booklet.

A student leaves school and walks south, arriving home after 18 min. The distance between the school and her home is 1200 m. At home, the student realizes she left a book at school. She walks back, arriving at the school 18 min later.

a. Determine the student's average speed as she walks home. Show your calculations and include units in your answer.

b. Describe the difference between the student's average velocity walking home and her average velocity walking back to the school.

c. Calculate the total distance the student walked. Show your calculations and include units in your answer.

d. Determine the final displacement of the student. Explain your answer.
Mark your answers to multiple-choice questions 33 through 43 in the spaces provided in your Student Answer Booklet. Do not write your answers in this test booklet, but you may work out solutions to multiple-choice questions in the test booklet.

**33** Which of the following always occurs when a light ray reflects off a mirror?

A. The speed of the light ray increases.
B. The direction of the light ray stays the same.
C. The frequency of the light ray decreases as it reflects and loses energy to the mirror.
D. The angle at which the light ray strikes the mirror equals the angle at which it reflects.

**34** Two positively charged objects are separated by a large distance. One of the positively charged objects is replaced by a negatively charged object, and the two objects are moved closer to each other.

Which of the following occurs in this situation?

A. The attractive force becomes a repulsive force, which increases as the objects move closer to each other.
B. The repulsive force becomes an attractive force, which increases as the objects move closer to each other.
C. The attractive force becomes a repulsive force, which decreases as the objects move closer to each other.
D. The repulsive force becomes an attractive force, which decreases as the objects move closer to each other.
35 Calorimeters are instruments used to measure heat. The diagrams below show a calorimeter before a metal sample is added and after the sample is added.

Calorimeter Before

Calorimeter After

Which of the following statements describes the flow of heat energy after the metal sample is added?

A. Heat energy flows from the stirrer to the thermometer.
B. Heat energy flows from the water to the metal sample.
C. Heat energy flows from the metal sample to the water.
D. Heat energy flows from the insulation to the thermometer.
The potential energy of a 77 kg diver standing on a 20 m high diving tower is 15,400 J. Two-thirds of the way down during the dive into the pool, his potential energy is 5,100 J. Neglecting air resistance, what is the diver's kinetic energy at this point?

A. 2,550 J
B. 7,650 J
C. 10,300 J
D. 12,850 J

A current of 2 A passes through an 8 Ω load. What is the potential difference across the load?

A. 0.25 V
B. 4.0 V
C. 10 V
D. 16 V

Which of the following has the greatest momentum?

A. 0.2 kg ball moving at 40 m/s
B. 500 kg car traveling at 16 m/s
C. 2000 kg truck traveling at 9 m/s
D. 50 kg child skateboarding at 4 m/s

Sound travels through air, steel, and water at different speeds. Which list is ordered from the substance that sound will travel through the slowest to the substance that sound will travel through the fastest?

A. air, water, steel
B. steel, air, water
C. water, air, steel
D. water, steel, air

What method of heat transfer allows the Sun's heat energy to reach Earth through the vacuum of space?

A. condensation
B. conduction
C. convection
D. radiation
41. The graph below illustrates the motion of a toy car during time intervals X, Y, and Z. The toy car is initially at rest. It is then pushed and released.

![Graph of Motion of Toy Car]

Kinetic friction is acting on the toy car during which of the following time intervals?

A. interval X only  
B. interval Y only  
C. intervals X and Z  
D. intervals Y and Z  

42. Work is performed on an object by raising it 2 m above the floor. Which of the following types of energy must change in this situation?

A. chemical energy  
B. magnetic energy  
C. mechanical energy  
D. thermal energy  

43. A worker in a warehouse pushes two wooden boxes across a floor at a constant speed, as shown in the diagram below.

![Diagram of Boxes]

The arrow in the diagram represents the force box 1 exerts on box 2. Which arrow represents the reaction force?

A.  
B.  
C.  
D.  

Questions 44 and 45 are open-response questions.

- BE SURE TO ANSWER AND LABEL ALL PARTS OF EACH QUESTION.
- Show all your work (diagrams, tables, or computations) in your Student Answer Booklet.
- If you do the work in your head, explain in writing how you did the work.

Write your answer to question 44 in the space provided in your Student Answer Booklet.

**44** A student heats a 200 g sample of water from 20°C to 80°C. The specific heat of water is 4.18 J/g • °C.

a. Calculate the thermal energy absorbed by the water. Show your calculations and include units in your answer.

The student then boils the water.

b. Describe what happens to the temperature of the water as it boils. Explain your answer.

The student repeats the experiment, this time placing a small block of iron into another 200 g sample of water. The specific heat of iron is 0.45 J/g • °C. Both the iron and the water are initially at 20°C and are heated to 80°C.

c. Compare the amount of thermal energy absorbed by the water in this experiment with your calculation in part (a). Explain your answer.

d. Describe how repeating the second experiment with a block made of a material with a greater specific heat will affect the amount of time it takes to heat the block. Assume the blocks have the same mass.
Write your answer to question 45 in the space provided in your Student Answer Booklet.

45  The diagram below is a simplified representation of the inside of a certain type of camera.

![Diagram of camera](image)

a. Identify and describe the wave behavior as the light rays pass through the glass lens.

b. Identify and describe the wave behavior as the light rays strike the mirror.

c. Copy the dotted box from the camera diagram into your Student Answer Booklet. Draw what must happen inside the box for light ray 2 to strike the viewfinder. Be sure to include the following:

- either a lens or a mirror that is labeled
- the path of light ray 2
- a line normal to the surface where light ray 2 strikes
Formulas

Average Speed \( = \frac{d}{\Delta t} \)

Average Acceleration \( = \frac{\Delta v}{\Delta t} \)

Average Velocity \( = \frac{\Delta x}{\Delta t} \)

\( v_f = v_i + a\Delta t \)

\( \Delta x = v_i \Delta t + \frac{1}{2} a \Delta t^2 \)

\( v_f^2 = v_i^2 + 2a\Delta x \)

Average Velocity \( = \frac{v_i + v_f}{2} \)

\( F = ma \)

\( P = mv \)

\( F = G \frac{m_1 m_2}{d^2} \)

\( V = IR \)

\( F = k \frac{q_1 q_2}{d^2} \)

\( P = IV \)

\( KE = \frac{1}{2} mv^2 \)

\( Q = mc\Delta T \)

\( PE = mg\Delta h \)

\( \lambda = \frac{c}{f} \)

\( W = Fd \)

\( \nu = f\lambda \)

\( T = \frac{1}{f} \)

Variables

\( a = \text{acceleration} \)

\( c = \text{specific heat} \)

\( d = \text{distance} \)

\( f = \text{frequency} \)

\( F = \text{force} \)

\( \Delta h = \text{change in height} \)

\( I = \text{current} \)

\( KE = \text{kinetic energy} \)

\( \lambda = \text{wavelength} \)

\( m = \text{mass} \)

\( p = \text{momentum} \)

\( P = \text{power} \)

\( PE = \text{gravitational potential energy} \)

Definitions

\( c = \text{speed of electromagnetic waves} = 3.00 \times 10^8 \text{ m/s} \)

\( G = \text{Universal gravitational constant} = 6.67 \times 10^{-11} \frac{\text{N} \cdot \text{m}^2}{\text{kg}^2} \)

\( k = \text{Coulomb constant} = 8.99 \times 10^9 \frac{\text{N} \cdot \text{m}^2}{\text{C}^2} \)

\( g \approx 10 \text{ m/s}^2 \)

\( 1 \text{ N} = \frac{\text{kg} \cdot \text{m}}{\text{s}^2} \)

\( 1 \text{ J} = 1 \text{ N} \cdot \text{m} \)

\( 1 \text{ W(watt)} = 1 \frac{\text{J}}{\text{s}} \)