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# Developing and testing microworld-based assessments for physical science

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RESEARCH REPORT

# Science ASSISTments: Developing and pilot testing middle school students' inquiry skills using a microworld for Kinetic and Potential Energy

An Interactive Qualifying Project Report

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## Abstract

This paper describes the creation of an online tutoring program aimed with the diagnoses and correction of common misconceptions associated with potential, kinetic, and mechanical energy. This is done through the use of interactive microworlds with simulations that mimic the physical movements of a ball. Testing was done on a group of middle school students from a local afterschool program from Massachusetts. Using the results, we then determined future work in order to enhance our microworld for production.

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# Introduction

## The Problem

The major paradigm of education is constantly changing. Recently, there has been a shift from an information-based economy to an innovation-based economy. This new environment requires what psychologist Robert J. Sternberg calls “successful intelligence,” something very different than what is taught in American school systems (Fadel, Honey, & Pasnick, 2007).

This is a problem that is made very obvious when the academic progress of American schoolchildren is compared directly against those of other developed nations (PISA 2006). This can be attributed to the fact that American schoolchildren are not taught how to critically analyze and interpret data given to them. Rather, emphasis is placed on rote memorization and test taking skills (Fadel 2007). Basic algorithmic processes receive more attention than critical thinking and analyzing skills during the critical points of education (Fadel 2007).

The National Frameworks for Science (NSES, 1996) claim that inquiry skills are necessary for the proper understanding of most scientific principles. Teaching these skills in a classroom environment is difficult as providing the necessary individualized attention is labor intensive and prohibited by high costs. Furthermore, the assessment of these inquiry skills is difficult through traditional means; proper assessment would require means in accordance with their instruction (Mislevy et al., 2002).

While teaching and tutoring are effective ways to develop science processing skills, proper assessment of these skills is difficult. In order to individualize tutoring to each student’s needs, constant and thorough science method evaluations are necessary. The National Science Education Standards (NSES 1998) were written to address this problem; however, the Science ASSISTments program sets forth to solve it (Gobert et al, 2007; Gobert et al, 2009).

## The Science ASSISTments Program

The purpose of the Science ASSISTments program, led by Dr. Janice Gobert at Worcester Polytechnic Institute, is to develop science inquiry skills in middle school students using interactive computer microworlds. These microworlds tutor and assess middle school students in the scientific skills of predicting, hypothesizing, experimenting within the microworlds, observing data, collecting data, interpreting data, analyzing data, and communicating and defending conclusions, all accrued from microworld experiments. In this way, more custom tailored tutoring may be individualized for each student (Gobert et al, 2007; Gobert et al, 2009) and strides can be made to meet national reform efforts (NSES, 1989).

One skill that must be mastered in order to complete all required tasks in a microworld correctly is a control for variable strategy (CVS). The CVS method holds all but the independent variable being tested constant and allows for data collection on the effects of the manipulation of that particular variable (Chen & Klahr, 1999). Studies argue that this procedural approach gives students a strong and necessary foundation in learning inquiry skills (Sao Pedro, Gobert, Heffernan, and Beck, 2009). Identification of the different kinds of variables and how to manipulate them, particularly independently, is believed to be the cornerstone of scientific experimentation. However, it is important to note that this fundamental skill to scientific literacy does not appear to develop naturally (Kuhn, 2005).

In addition to microworld-based experiments guiding students through a step-by-step process designed for the completion of inquiry skill based problem sets, the ASSISTments software is also designed to collect data pertinent to the student's performance in the microworld. Teachers are able to assess students based on ASSISTments generated reports that score the students according to utilization of inquiry skills and content knowledge. They are then able to track a student's performance through the logs that are generated as students engage in the microworld-based activities. In this way, the Science ASSISTments learning environment is making strides in useful and informative assessments of a student's progress in the areas of science knowledge and inquiry skill development.

The content these microworlds are designed to cover is closely based on the learning strands presented in the Massachusetts Curricular Frameworks (Massachusetts Department of Education, 2006). In this way, students can be engaged in interactive frameworks that parallel their course of study. In the future, the microworlds may even be utilized to tutor students in effective inquiry and experimentation skills. It is also possible that deepening the student's scientific content knowledge through the use of interactive microworlds will positively impact the student's scored on the MCAS, a standardized test that all students in the Massachusetts public school system are required to pass in order to receive their high school diploma. (Gobert, 2009). The MCAS is a standardized test that all students in the Massachusetts public school system are required to pass. Furthermore, it is expected that the ASSISTments project will improve scientific literacy through the honing of inquiry skills and deepening of content knowledge (Gobert et al, 2007; Perkins, 1989).

# Background

## Problems with Science Learning

Reports have shown that students in the United States are not performing as well in science achievement exams as other countries and states. The TIMSS 1999 Benchmarking Reports (*TIMMS*) studied student performance in mathematics and science across the country compared to other countries. The reports show that the top five countries in 1999 for performance in science were China, Taiwan, Singapore, Hungary, Japan, and the Republic of Korea. While the students from the United States had an average score above the international average in science achievement, the United States was still in the middle of the rankings. The United States ranked $35^{th}$, out of 65 participating groups. Massachusetts ranked $25^{th}$ among all of the states in the same study. Higher achievement in the science assessment was related to a higher emphasis that teachers placed on experimentation and practical investigation. Schools in the United States taught science as a single subject, unlike other countries who taught the classes as separate entities such as biology, physics, and chemistry (Martin, et al., 2001).

A later study yielded similar results to the TIMMS report. The PISA Reports from 2006 conducted by the Organization for Economic Co-operation and Development further confirm the conclusion that students in the United States are achieving scores lower than those in other developed countries. In 57 participating countries, the United States ranked $29^{th}$ in the science assessments. The average score from students from the United States was below that of the average of all students tested. The top five countries in this report were Finland, China (Hong Kong), Canada, Chinese Taipei, and Estonia (*Programme for International Student Assessment).*

## Previous Relevant Conducted

There are some previously conducted projects and studies that relate to the Science ASSISTments project. A study was conducted by faculty at the University of Wisconsin-Madison and the University of Pittsburgh to see how sixth grade students understand the goals and strategies of scientific experimentation. The study also aimed to determine if the students' understanding of the goals and strategies could be deepened through effective teaching. Five teachers and their students participated in the study. These participants first went through a baseline interview to assess students' understanding of experimentation, and then went through a three-week period where a special experimentation unit was taught in the classrooms. Finally, the participants went through another interview to reexamine the understanding of experimentation. This project suggests that students learn about experimentation best through longer periods of real investigation, rather than in shorter labs with unrelated activities that feature a few main procedures. Experimentation in the classroom was able to stimulate students' learning about scientific concepts and experimentation itself (Glaser, et al., 1995).

Another study conducted by faculty from the Max Plank Institute for Human Development and the University of Munster set out to show that experimentation with built-in instruction is better than experimentation where students must arrive at their own means of learning. The study focused on two approaches to teaching; high instructional support (HIS) and low instructional support (LIS). In the HIS groups, students were asked to have group discussions with statements provided by the teachers that related to or did not relate to ideas and hypotheses that students created. This method enabled the teacher to get an understanding of the students' knowledge. In the LIS groups, students were in group discussions without statements relating to their hypotheses, with the teacher as just a supervisor. This method allowed students to react to others' comments. Students originally focused on only one aspect of whether an object would float or not, rather than a combination of properties; the mass (light things float), the volume (large things sink), or the form (everything with holes in it will sink). Students in the HIS groups were able to better understand why some objects float in water and others do not, while the students in the LIS group showed a decline in understanding (Hardy, et al., 2006).

An experiment designed and conducted by the late Ann Brown, a former faculty member at University of California-Berkeley, set out to change and improve the structure of learning in classrooms. Brown had students in one class follow a "traditional" curriculum of only being taught in the classroom. Another group followed the same curriculum, but also was encouraged to "engage in self-reflective learning and critical inquiry." This experiment followed a similar pattern of testing to the other studies, with a pretest, a learning period, and a posttest some time after. A seventh-grade student involved in the traditional setting could give a textbook definition of photosynthesis, but did not completely understand the food chain, as evidenced by her responses to questions about what would happen if there were less sunlight. She explained that less sunlight would kill the plants and that animals that relied on the plants could become nocturnal, but because these animals could not see the food, they would starve to death. Another student, in the research group, was able to identify important characteristics of carnivores in the pretest, such as speed, body size, and teeth shape. He did not completely understand the concept of evolution, and answered that if people choose to be vegetarians so could a cheetah when asked if cheetahs could survive without any game. In the posttest, this same student was able to make analogies to a cow's digestive tract, and answered that the cheetah's digestive system and teeth were too different to be able to switch to vegetarianism in one animal's lifetime. Brown concluded that the students in the research classroom showed much greater improvement over a year than the students in the traditional classroom (Brown, 2006).

Together these three studies show that experimentation with some instruction included can be a strong method in enabling students to understand scientific concepts in both an academic setting and a real-world setting.

## Differences Between Science ASSISTments and Other Programs

The Science ASSISTments program (http://users.wpi.edu/~sci_assistments/) is designed to assess a student for content knowledge and to assist the student with understanding concepts that he or she might not fully grasp. The ASSISTments program uses inquiry as its main way to teach students content knowledge. Inquiry skills are not typically assessed in state-based science tests. Until recently, hands-on activities were used without providing scaffolding techniques to guide the student through misunderstandings. The scaffolding strategy is a simple system in which the student is guided to exercise the microworld activities in the most efficient manner. In the Science ASSISTments project, students are able to utilize scaffolding and real-time learning to more fully participate in inquiry learning. Scaffolds provide helpful hints to break the problem into smaller, more manageable, parts. When the answers to these small parts are put together, the student should be able to understand the concepts presented in the main question.

One main difference between the Science ASSISTments program and other science-based learning programs is that the ASSISTments program logs data of the student's every action in the program, including how long a question was looked at and how each question was answered. Teachers can then extract the data created to assess the students' understanding of material to custom-tailor their instruction. This allows the teacher to focus more on harder concepts so students can better understand all areas relating to a topic. Other programs which try to teach or guide in understanding of science concepts include Concord Consortium's ITSI (*Information Technology in Science Instruction, Concord Consortium*) and Modeling Across the Curriculum (mac.concord.org) projects and University of California – Berkeley's Thinker Tools (*Thinker Tools*, University of California-Berkely). These programs log data of how questions were answered, but do not attempt to adaptively guide students' inquiry, as the Science ASSISTments projects does.

The Modeling Across the Curriculum project is related to the *ITSI* project. It includes various science activities relating to chemistry, biology, and physics. The physics activities are called Dynamica, and is the most closely related to the group's work described in this document. None of the activities in the Dynamica set relate to potential or kinetic energy like the group's work in Science ASSISTments. The *Thinker Tools* project focuses more on inquiry skills rather than content skills, so it also does not have activities relating to potential and kinetic energy.

Another difference between the programs is that the Science ASSISTments program allows educators to create their own problem sets. This allows for the tested content to match what is being taught in the classroom. It also allows for the utilization of external material such as Flash, QuickTime, Shockware, Windows Media, or Real Media files (called microworlds), or photographs. The Science ASSISTments energy IQP group used this feature to embed custom-created Flash programs to assess and assist misconceptions related to kinetic and potential energy.

## Misconceptions

Misconceptions the group tried to address focused on kinetic and potential energies of systems. One misconception directly tested in the microworld questions was that stationary objects do not have energy. Another misconception directly tested in the questions was that energy is not conserved. That is, energy does not change from one form to another and can be created or destroyed. These two misconceptions are discussed in New York's Energy Research and Development Authority's *Energy Misconceptions* guide (New York State. Energy Research and Development Authority, 2010). The group also directly addressed the misconception that gravitational potential energy depends only on the height of the object. This misconception was addressed in the first ball-drop microworld, and is discussed in Valerie Talsma's paper *Children's Ideas in Science* (Talsma, 2008).

Other misconceptions not directly asked about in the Science ASSISTments project, but which could be addressed with our microworlds, were found in a paper by Colin Kruger, in which teachers were interviewed about their own misconceptions about energy (Kruger, 1990). The misconception that kinetic energy does not depend on speed could be addressed with the skate rink microworld, which logs the current speed of the ball as students press the record button. An observant student could recognize that with more velocity, there is more kinetic energy in the system. The statement that gravitational energy is misunderstood or not recognized could be addressed with either microworld, as the graphs in the ball-drop world and the tables in the skate rink world show potential energies; which students could deduce are due to the effects of gravity.

## Massachusetts Curriculum Framework

The Science ASSISTments project set out to follow the Massachusetts Science and Technology/Engineering Curriculum Framework (Massachusetts Department of Education. *Massachusetts Science and Technology/Engineering Curriculum Framework*). This ensured that the content and methods were not too far above or below the level middle school students should be. Pages 61-68 of this document (Appendix A) outline how students in the targeted grade levels learn and the learning standards that students should know in the selected grade range. This document states that:

> "In grades 6–8, students still need concrete, physical-world experiences to help them develop concepts associated with motion, mass, volume, and energy. As they learn to make accurate measurements using a variety of instruments, their experiments become more quantitative and their physical models more precise. Students in these grades are able to graph one measurement in relation to another, such as temperature change over time. They may collect data by using microcomputer- or calculator-based laboratories (MBL or CBL), and can learn to make sense immediately of graphical and other abstract representations essential to scientific understanding" (page 61).

The group followed learning standard 13, of the *Forms of Energy* portion of the *Physical Sciences (Chemistry and Physics), Grades 6-8* section of the document (page 68). This learning standard recommends that students in the 6th-8th grades be able to "Differentiate between potential and kinetic energy" and "Identify situations where kinetic energy is transformed into potential energy and vice versa" (page 68). This second part of the learning standard was interpreted by the group to include conservation of energy, to show students that the total energy of a system always stays the same.

# Methods

## Participants

The target group for the ASSISTments project is middle school students and teachers in the Worcester, MA public school system as well as surrounding areas. Worcester is one of the largest cities in Massachusetts with an estimated population of 182,596 comprised of many different ethnicities (Monahan, 2009).

## Procedure

Each of the student participants was brought into a computer lab on the Worcester Polytechnic Institute campus in Goddard Hall Laboratories and seated at an individual computer at least one computer away from his/her neighbor. The students each logged into a previously made ASSISTments account or created a new one. Each of the participants' spoken responses was logged on a personal voice recorder. If the student required help to proceed along with their current microworld, minimal assistance was administered until the student could move along on his/her own accord.

The students were first asked to complete a demographics section in order to accurately fine-tune the ASSISTments program in order to classify the students based on age and level of prior scientific knowledge, interest, and academic proficiency. Secondly, the students were asked to complete a quick Vocabulary Pre-Test in order to give them a familiarity of terms including dependent and independent variables. Afterwards, a Content Knowledge Pre-Test was administered that measured the students' knowledge of potential, kinetic, and total mechanical energy and assessed any previous misconceptions. Next, the students were given the microworld activities to complete (which were programmed by the Science ASSISTments team). They would create a hypothesis and examine the effects on the simulation as specific independent variables were changed. After experimenting with the simulation, hypotheses could be tested and interpreted for results. Each of the three microworld activities had its own embedded assessments to revaluate progress. After the microworld, the students were given a Content Knowledge Post-Test identical in form to that of the Pre-Test to measure improvement in the subject matter.

## Materials

### Demographics

The first part of the ASSISTments program is a short demographics section designed to classify each student based on several useful factors. The students are asked immediately for their sex, age, and grade level. Afterwards, more specific questions are asked that highlight many aspects that are important to ASSISTments research. For example, "Which subject(s) do you like the most at school?" Next, "How would you rate your enjoyment for learning Science?" Then we ask each student for their average grades in science classes, and their grades overall.

## Vocabulary Pre-Test (Appendix B)

The vocabulary pre-test was designed to measure whether or not students understand the meaning of independent and dependent variables. If a lack of knowledge is present, various scaffolds are present to quickly teach the difference between these. The first is an example with a hypothetical experiment with the dependent and independent variables labeled. After that, if an incorrect response is given, an explanation is given as to why it is incorrect and the student is allowed to choose again. Without a basic understanding of what independent and dependent variables are, it will be impossible to proceed along with the subsequent activities.

## Content Knowledge Pre- and Post-Test (Appendix C)

The pre- and post-tests are designed to measure each students prior knowledge of potential, kinetic, and mechanical energy, and the level each student gained understanding of these concepts following the microworlds. The pre-test is identical to the post-test and therefore will only be described in detail once.

### *Knowledge Pre- and Post-Test 1*

The first of the four pre-test sets centers on the definitions of kinetic, potential, and mechanical energy. A solid understanding of the differences of each form of energy will allow the student to test well for these questions.

The first question started with a picture of a tree with an apple hanging from one of its branches. The student was then asked, “An apple is hanging from a tree. Does it have energy in relation to the ground?” The answers, “Yes”, “No”, and “there is not enough information to answer the question" are provided.  This question is a starter that serves as a baseline to see whether the student even understands the concept of energy regardless of its categories.

Another picture is then portrayed where the apple is falling from the branch towards the ground. The second question asks, "Shortly after, the apple falls down from the tree. When, during the descent, does the apple have the most mechanical energy?"  The available answers are, "Right after it starts to fall down", "Halfway", "Right before it reaches the ground", "The apple always has the same mechanical energy", and "None of the above".  The purpose of this question seeks to see whether the student understands the definition of mechanical energy and its relationship to the total energy of the system.

The last two questions in the set are worded exactly as the previous question except that all instances where "mechanical energy" is used are changed to "potential energy" and "kinetic energy" respectively.  The choices for answers are also identical except for the same change. The purposes of these questions are to continue with the testing of definitions; in this case, whether the student understands the differences between kinetic, potential, and mechanical energy.

### *Knowledge Pre- and Post-Test 2*

The second part of the pre- and post-test consists of a single question, "After falling some distance, what happens to the apple's potential energy?"  The student has the option of answering, "Some of it is destroyed", "Some of it is transferred to kinetic energy", "Nothing happens to the potential energy", "More potential energy is created".  This lone question serves the important purpose of determining whether or not the student is familiar with the concept of conservation of energy.

### *Knowledge Pre- and Post-Test 3*

The next part of the pre- and post-test allows for the examination of whether each student can understand qualitative comparisons in a multiple body system. A picture of another tree is presented, this time with two apples of equal mass. The first apple (A) is hanging much higher than that of the second apple (B). “Apple A starts to fall and reaches the height of apple B, which has not yet fallen. Which of the two apples has more kinetic energy?” The answers allowed are, “Apple A”, “Apple B”, and “They both have the same amount of kinetic energy”.

The next two questions are identical to that of the first one except that, once again, all instances where “kinetic energy” is used are changed to “potential energy” and “mechanical energy” respectively. Asking these three questions allows the instructor to gauge the students’ qualitative understanding of quantity of each form of energy and how it relates to another body in the system.

### *Knowledge Pre- and Post-Test 4*

The last of the pre- and post-test sets centers on the effect mass has on potential, kinetic, and mechanical energy. Each of the previous pre- and post-tests measured their specific concentration of comprehension using height as the independent variable of choice. This last set allows for the testing of mass as the conceptually more difficult of the two variables. The first question states, “Now we will look at two apples at the same height but with different masses.

Apple A has more mass than apple B.  Which apple has more potential energy?"  The options for answering are, "Apple A", "Apple B", and "They both have the same amount of potential energy".  This helps to combat the idea that gravitational potential energy is only affected by the height of the object.

The second question is very similar to the first, "Both apples fall from the tree. Right before they reach the ground, which one has more kinetic energy?"  The selection of answers is of course, "Apple A", "Apple B", and "They both have the same amount of kinetic energy".  By putting both objects in motion and at the instance right before they hit the ground, any misconception about the effect of mass on potential energy can be put aside.  This limits the testing to the incorrect notion that the distance of the fallen height is the only factor to an object's kinetic energy.

## Physics Microworlds & Tasks

### Microworld One: Relationship of Mass and Height Exploration (Appendix D+E)

#### *Objective*

The first of the microworlds was created to incorporate an understanding of the relationship between mass and height to kinetic, potential, and mechanical energies.  Comprehension of mass and height and its effect on kinetic, potential, and mechanical energy is paramount to their understanding of the principals of the conservation of energy.  The pretest was designed to measure students' previous knowledge of mass and height in their relation to energy.  The first microworld is designed to reinforce these concepts.  For those students who did not perform well in the pretest and are relatively unfamiliar with the connection of mass and height to energy, the microworld will assist by providing guided experimentation to structure this concept. For those already partially familiar with the topic, the microworld will reinforce their understanding and allow for deeper learning.

### *Experiment One: Mass Exploration (Appendix D)*

The first section of the microworld allows the student to “play around” with the structure of the microworld. This is designed to provide the student with an opportunity to learn the controls of the microworld without the necessity of manipulating variables or measuring specific changes. The design of this first part is simply that of a ball dropping from a preselected height. A student may choose to change the height of the ball, the mass of the ball, or both.

After playing with the design for however long he/she may choose, the student is prompted with the question, “Now that you've played with our microworld, do you think the mass of the ball affects the amount of initial potential energy it has?” This obviously grants the option of the answers, yes, no, and I don’t know. Directly after this, the student is asked, “Do you think the mass of the ball affects the amount of final kinetic energy it has?” which is granted the same options for answers. The next question asks, “How does mass of the ball affect the amount of mechanical energy it has?” The answers for this are “As mass increases mechanical energy increases”, “As mass decreases mechanical energy decreases”, “All of the above”, or “Mass of the ball does not affect mechanical energy”; the correct answer of course being “All of the above”. These questions are included to present a baseline to judge a student’s knowledge and understanding of the material in a fashion other than that of the pretest. They are written in a way that directs students towards the concepts we are intending to structure.

After these pre-microworld questions, the student is then allowed to work with the full version of the microworld design. The student is prompted with the message, “Now, conduct some experiments to test your above predictions and explore the relationships between mass and three forms of energy: kinetic, potential and mechanical energy.” The student is first given the tools to create a hypothesis to test. From pull down menus, a hypothesis sentence is created that he/she will be permitted to test. The structure of the hypothesis builder is as follows: **If I change the** [mass of the ball, height of the drop] **so that it** [decreases, increases] **then the** [initial kinetic energy, initial potential energy, initial mechanical energy, final kinetic energy, final potential energy, final mechanical energy] [decreases, increases, won’t change].

After choosing from the sets of pull downs, the student will test their hypothesis by using the microworld and changing specific variables to observe the effect; in this case, the student should only be changing the mass of the ball. If the student attempts to change the height of the ball during this round, he/she will be reminded by a set of scaffolds that they should be changing only the mass if they are to be determining the effect of mass. The effect on the ball’s kinetic, potential, and mechanical energy is measured quantitatively through the use of three graphs that plot kinetic, potential, and mechanical energy, respectively, against time. In addition, a table is filled out in the background that logs trial numbers against the independent variables: Mass of the ball and the Height of the drop; along with the dependent variables: Initial Potential Energy, Initial Kinetic Energy, Initial Mechanical Energy, Final Potential Energy, Final Kinetic Energy, and Final Mechanical Energy.

By changing the specific variable and watching its effects upon kinetic, potential, and mechanical energy, the student is then ready to analyze their previously created hypothesis by creating a “data interpretation” which is identical in structure to that of the hypothesis builder. The student does this by building an interpretation and selecting from the table which trial runs they wish to support their analysis with. After this, the student has the option of building and analyzing as many hypotheses as they wish in addition to running as many trials as is needed to fully grasp the relationship between mass and energy. The student is also given the option of opting to move on at this point.

After the microworld, each student is then asked a very similar set of questions to those posed before. These embedded assessments are used specifically to compare to the questions posed before the microworld in order to measure an immediate level of improvement, or lack thereof, in the learning objective. It takes the form of three questions, each with two parts. All three questions are worded identically, “Does the mass of the ball affect the amount of _______ energy it has?” where the blank is potential, kinetic, or mechanical. The second part of each question prompts the student to, “Explain your answer as if you were writing to a friend that doesn't know anything about the relationship between mass of the ball and the amount of _______ energy it has,” where the blank is again potential, kinetic, or mechanical in that order. The explanation after each question serves to measure their reasoning about the mass/energy relationship.

### *Experiment Two: Height Exploration (Appendix E)*

The second part of the first microworld is based on the relationship of height to potential, kinetic, and mechanical energy. In structure, the second part of the microworld is identical to that of the first. In fact, the only differences are the deletion of the activity phase at the beginning of the problem set and the overall replacement of the phrase “mass of the ball” to “height of the ball” in every question and description. Like the first microworld, there is a set of embedded assessments designed to measure understanding of the concept both before and after the microworld design. The microworld itself is identical save for the change in the desired variable manipulation; that being height instead of mass. Once again, the students are asked to create hypotheses, test each one, and analyze their results.

## Microworld Two: Exploration of the Conservation of Energy Principle (Appendix G)

### *Objective*

The objective of the second microworld is to solidify understanding of the conservation of energy. In this microworld, students are able to manipulate both independent variables, the mass and the height of the ball, to test their effect on potential, kinetic, and mechanical energy. The activity and its questions are designed to alleviate common misconceptions and build comprehension of the law of conservation of energy, a concept that is often a subject of difficulty due to its relatively abstract nature. The construct of the activity is that of a ball rolling back and forth, down and up a ramp. This scenario is useful because it allows the student to repeatedly see that energy is not destroyed, but instead is transferred to another form of energy. It also allows the student to qualitatively see that the mechanical energy of a system does not change with ball position or time.

By design, this microworld gives the student more freedom with variables. This allows the student to take what he/she was meant to learn in the previous microworlds and apply it to discover the new concept. For this reason, the student is not asked to manipulate any specific variable in any order. The point is to see that, regardless of the variable changed, energy is not destroyed or added at any point but is conserved.

### *The Experiment*

Like the beginning of the last microworld, the student is first given a basic version of the microworld in order to explore without the necessity of controlling variables and monitoring data. The student may change mass of the ball and the height of the ramp (and in turn the ball's starting location) but none of the dependent variables are shown. Once the student understands the structure and format of the microworld, he/she is prompted to select the answer, "Ok, I understand".

After the beginning exercise, each student is given the question, "Do you think the ball's energy is ever destroyed as it rolls in the rink?" The options for answering are, "Yes" or "No". The point of this simple, singular question is the same as with the previous microworlds. It is designed to provide an embedded assessment to measure immediate knowledge of the concept of conservation of energy. In addition to this, the question primes the student to think about the changing of variables in a sense other than that of the additive properties of kinetic and potential energy. Instead, they see that they should be focusing on the nature of the energies of the ball, and what happens to that energy as the simulation is played out.

Once this question is answered, the full microworld design is shown and the student may begin with the activity. As with the previous construct, the student is first asked to create a hypothesis to test using a series of drop down boxes. "**When the ball** [rolls down the rink, rolls up the rink] **the** [potential energy, kinetic energy, mechanical energy] **will** [be transformed into, be destroyed, be created, stay the same] [potential energy, kinetic energy, mechanical energy, (end of sentence)]. Once a hypothesis is constructed, the microworld is activated. Here, the students may change both independent variables; no scaffolds are present to direct their experimentation. However, unlike the previous microworld, the dependent variables are not graphed, but are measured using qualitative "energy bars". There are three unmarked bars; one for each potential, kinetic, and mechanical energy of the ball. As the ball runs back and forth, up and down the ramp, the bars fill and empty (based on real quantitative calculations that are not shown but underlay the programming of the microworld, done by the Science ASSISTments team). In addition, the lengths of the bars change accurately with total quantity of energy so as to visually demonstrate the previous microworld's lesson that the amount of energy is both dependent on the height and mass of the ball and that the amount of mechanical energy is additive to the kinetic and potential energy. The bars themselves are designed to show that energy is not created or destroyed, but that it flows from one form of energy to the other. It also shows that the energy transfer is not instantaneous, but is gradual based on the movement of the ball.

Additionally, each run is not automatically logged in a table due to the infinite nature of each run. Instead, the student is instructed to click "Record" at any time believed to be significant to measuring the change in energy. When enough measurements are taken at any run, the "Reset" button allows the changing of any variable and more measurements to be recorded at the students' discretion. When the student is done taking measurements, a data interpretation tool pops up in the same manner as the previous microworld. The student has the option of checking off the trials in the record table that represent their interpretation, as specified by the data interpretation widget (designed by the Science ASSISTments Team). After hypothesizing, experimenting, and interpreting as many trials as are needed, the student is then allowed to move onto the latter half of the microworld.

After the activity, the student has two more questions to answer. To follow with the aspect of embedded assessments, the students are asked a question similar in form to the one asked before the activity. "During the continuous movement of the ball, is energy ever destroyed?" The change in wording is meant to provide a relation to the microworld simulation. This way, a connection can more easily be created between the purely scientific analysis that energy is neither created nor destroyed and the real life scenario of a ball rolling on a ramp. In uniformity with the previous microworlds, the student is then asked, "Please explain your answer as if you were explaining it to a friend that doesn't know anything about potential, kinetic, and mechanical energy." This is done to assess the knowledge in a more fine-grained way than a simple yes/no answer can provide. It compels the student to think back to the reasoning formulated when asked to create an interpretation of the hypotheses and experiments in the activity. Again, this allows for a connection between the scientific and the observation.

## Scaffolding

The programming and official design of each of the three microworld activities was created by the Science ASSISTments team (http://users.wpi.edu/~sci_assistments/ ). Each of the three designs scaffolded the students to use Control for Variable Strategy (CVS) to conduct experimental trials in order to interpret the provided simulation. This requires that the student only change the target variable that is being tested-while holding all other variables constant. Programmed into the microworlds are a series of scaffolds that alert the student when this is not actively being accomplished.

There are two main sets of scaffolds and three level to each: the first activates when the student is controlling the wrong independent variable from his/her hypothesis, the second fires when the student is not controlling for either variable. Each set of scaffolds has three different levels. In order for the first level to fire, the student must incorrectly run two trials. Each incorrect trial after leads to another, more direct scaffold telling the student to control for the independent variable from the previously created hypothesis is given.

If a student incorrectly runs two trials by using CVS on the wrong independent variable, a scaffold will activate that says, “Based on your trials, we see that you are not changing the variable you wanted to test in your hypothesis.” It continues on, “Suggestion: Now run as many trials as needed to test your hypothesis. You can look back at your hypothesis.” If the student continues changing the variable not in his/her hypothesis, another scaffold activates; “In your hypothesis you stated that you were going to change the [IV] of the ball.” It then prompts them to run as many trials as needed. The last level of scaffold states, “Change the [IV] of the ball and run the number of trials you need to test your hypothesis.”

The other form of scaffold only activates when the student does not use CVS at all. The first level of scaffold states, “Based on your trials, we see that you are not changing the variable you wanted to test in your hypothesis. Suggestion: Now run as many trials as needed to test your hypothesis. You can look back at your hypothesis.” If the student continues to not correctly utilize CVS the second level of scaffold is shown; “In your hypothesis you stated that you were going to change the [IV] of the ball.” Again it prompts the student to run more trials. The last level of scaffold is just as direct as the previous set, “Change the [IV] of the ball and run the number of trials you need to test your hypothesis.”

### Data Collection

The ASSISTments website automatically grades each student and provides detailed information on the performance of the test group (or class). This includes scores of individual students, scores on individual questions, and access to open response answers. However, the website does not provide access to the students’ activities inside the programmed microworlds. For this, the Science ASSISTments team was able to program and output a log file for each student. This was transferred as an Excel document and manually sifted through for important information.

## Results

The following section presents a fine grained summary of the students’ interactions with ASSISTments and the microworld activities. Their answers to the tests and assessments were gathered from the ASSISTments system while their sequence of interactions within the microworlds were gathered from the microworld log files, which provide a much more detailed record of the students' actions within the microworlds.

The following four tables provide a summary of how each student performed within each embedded assessment. Along with the scores on the pre and post embedded assessment is the amount of scaffolds fired during the activity, the amount of trials performed during the activity, the time between the scaffolds are fired and the student's next action according to the microworld log file, and whether the student's next action was to proceed to the analyze section of the activity.

**Table 1: Individual Student Performance for the Freefall (Mass) activity**

| Student | Freefall (Mass) Embedded Pre Assessment | Scaffolds | Trials | Time Spent Reading Scaffold (sec) | Analyze After Scaffold? | Freefall (Mass) Embedded Post Assessment |
|---|---|---|---|---|---|---|
| 1 | 0% | 1a | 3 | 3 | No | 33% |
| 2 | 0% | | 1 | | | 1 |
| 3 | 33% | | 8 | | | 0% |
| 4 | 67% | 2a | 3 | 14 | Yes | 67% |
| 5 | 0% | | 6 | | | 33% |
| 6 | 67% | | 2 | | | 100% |
| 7 | 33% | 2a, 1a | 7 | 1,0 | No, Yes | 100% |
| 8 | 33% | 1a | 4 | 3 | No | 100% |
| 9 | 0% | 1a | 6 | 8 | No | 1 |
| 10 | 0% | | 1 | | | 33% |

Table 2: Individual Student Performance for the Freefall (Height) activity

| Student | Freefall (Height) Embedded Pre Assessment | Scaffolds | Trials | Time Spent Reading Scaffold (sec) | Analyze After Scaffold? | Freefall (height) Embedded Post Assessment |
|---|---|---|---|---|---|---|
| 1 | 0% | | 7 | | | 67% |
| 2 | 0% | | 2 | | | 67% |
| 3 | 67% | | 1 | | | 100% |
| 4 | 67% | 2a | 2 | 1 | Yes | 33% |
| 5 | 67% | | 0 | | | 67% |
| 6 | 67% | | 1 | | | 100% |
| 7 | 67% | | 3 | | | 100% |
| 8 | 0% | 1a | 4 | 2 | Yes | 67% |
| 9 | 67% | | 3 | | | 67% |
| 10 | 67% | | 1 | | | 33% |

Table 3: Individual Performance for the Skate Ring Activity

| Student | Skate Ring Pre Assessment | Trials | Skate Ring Post Assessment |
|---|---|---|---|
| 1 | 100% | 1 | 100% |
| 2 | 100% | 2 | 100% |
| 3 | 0% | 1 | 0% |
| 4 | 0% | 1 | 100% |
| 5 | 100% | 0 | 0% |
| 6 | 100% | 1 | 0% |
| 7 | 100% | 0 | 100% |
| 8 | 0% | 0 | 0% |
| 9 | 100% | 2 | 100% |
| 10 | 0% | 1 | 0% |

Table 4: Individual Performance for Content Knowledge Pre and Post Tests

| Student | Pre Test 1 | Pre Test 2 | Pre Test 3 | Pre Test 4 | Post Test 1 | Post Test 2 | Post Test 3 | Post Test 4 | Gain |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 25% | 0% | 0% | 50% | 50% | 0% | 67% | 50% | 23% |
| 2 | 75% | 0% | 0% | 100% | 25% | 0% | 67% | 0% | -21% |
| 3 | 25% | 0% | 0% | 100% | 50% | 100% | 67% | 0% | 23% |
| 4 | 25% | 100% | 0% | 0% | 50% | 0% | 67% | 50% | 10% |
| 5 | 50% | 0% | 67% | 0% | 25% | 100% | 33% | 50% | 23% |
| 6 | 25% | 100% | 33% | 100% | 0% | 0% | 67% | 100% | -23% |
| 7 | 50% | 0% | 33% | 0% | 25% | 0% | 33% | 100% | 19% |
| 8 | 50% | 0% | 0% | 50% | 0% | 0% | 0% | 50% | -13% |
| 9 | 25% | 0% | 33% | 50% | 50% | 100% | 0% | 0% | 10% |
| 10 | 25% | 0% | 67% | 50% | 25% | 0% | 33% | 50% | -8% |

## Student One:

### About the Student

Student One is a thirteen year old male in the seventh grade. According to his responses in the demographics portion of the test, he likes math and social studies classes the most. He enjoys learning science sometimes and finds science classes somewhat easy. In his science classes, his grades are generally in the C range and in the B range for all classes.

### Dependent/Independent Variable Knowledge

In the vocabulary section, Student One correctly identified what independent and dependent variables are, but answered that he is very unsure about his understanding of the vocabulary.

### Content Knowledge Pre Test

In the first pretest section, Student One stated that there was not enough information to determine how much energy the apple in the tree had in relation to the ground. He also answered that as the apple falls, it has the most mechanical energy right after it starts to fall and has the most potential energy right after it starts to fall as well. When asked "when, during its descent, does the apple have the most kinetic energy", Student One stated that neither "right after it starts to fall," "halfway," "right before it reaches the ground," nor "the apple always has the same kinetic energy" is the correct answer.

For the second pretest section, Student One answered that some potential energy is destroyed after falling some distance.

In the third pretest section, when asked which of the two apples at the same height has more kinetic energy, Student One answered that both the apple at rest and the apple in motion have the same amount of kinetic energy. He chose the apple at rest as having the greater mechanical energy between the two.

In the fourth pretest section, Student One answered that both apples (each at rest, of different mass, but equal height) have the same amount of potential energy. He also chose the apple of larger mass as having more kinetic energy when it falls than the apple of smaller mass.

Student one demonstrated a very poor initial understanding of the material to be presented in the microworld. This is a problem in that the microworld was originally designed to work with students that have already been exposed to the concepts and to test them on common misconceptions. It was never intended to be a sole tutoring platform with which to teach the material as a first experience.

## Freefall Microworld (Mass)

### *Embedded Pre Assessment*

Student One did not know when asked whether the mass of the ball affects the amount of initial potential energy it has. He answered that "mass does not affect the amount of final kinetic energy it has" and "that as mass decreases, mechanical energy decreases".

### *Freefall Activity*

During the activity, Student One hypothesized that "If I change the mass of the ball so that it decreases then the potential energy increases." He then moved on to the experiment section of the activity to run a trial as evidenced by his log files (the logs files being the record of data collected from each experiment for each student; they are used from this point forward to quantify every student's performance). After running the first trial without changing any of the variables, he decreased the drop height. Since he changed a different variable from the one mentioned in his hypothesis, the first level of scaffold 1 fired. He closed the scaffold after 3 seconds, perhaps giving him some time to quickly scan the message's content. He then moved on to the analyze portion after 3 seconds. He formulated the interpretation "When I changed the mass of the ball so that it decreased the initial potential energy increased." He did not provide any supporting trials.

Student One then went on to create another hypothesis. This time he hypothesized: "If I change the height of the drop so that it decreases, then the initial potential energy increases." He did not run any trials and moved on to analyze. His first interpretation was "When I changed the mass of the ball so that it decreased, the initial potential energy increased" and did not provide any supporting trials. His second interpretation was "When I changed the height of the drop so that it increased the initial kinetic energy decreased" and again did not support this with trials.

### *Embedded Post Assessment*

When asked whether the mass affects the initial potential energy it has, he answered that it does. He explained his answer with, "the mass of the ball affects the initial potential energy. i know this because when i increased the mass the ball droped [sic] slower and that means the energy decreased". When asked if the mass of the ball affects the final kinetic energy it has, he answered no, with the explanation "no it dosnt[sic]. i know this because nothing happened to it after changing the mass" When asked whether the mass of the ball affects the amount of mechanical energy it has, he answered no with the explanation, "it dosnt [sic]. i know this because when I changed the mass nothing happened [sic]."

While his language may not indicate that he was actively engaging the microworld, the results show that he was putting forth effort. Student One ran several trials, and while not using control for variables strategy, was still able to realize many of the physical aspects of mass and height. His answers were not entirely consistent with what went on physically. However, as stated before, this is remarkable considering he had little to no prior experience with the subject matter.

## Freefall Microworld (Height)

### *Embedded Pre Assessment*

Student One answered "No" when asked whether the height of the ball affects the amount of initial potential energy it has. When asked whether the height of the ball affects the amount of final kinetic energy it has, he answered that it does not. When asked how the height of the ball affects the amount of mechanical energy it has, he answered that "as height increases mechanical energy increases and as height decreases mechanical energy decreases".

### *Freefall Activity*

Student One hypothesized that “If I change the mass of the ball so that it increases then the initial mechanical energy doesn’t change.” He then moved on to conduct one experiment before proceeding to the analyze section. He formulated the interpretation “When I changed the mass of the ball so that it decreased the initial mechanical energy didn’t change”, but provided no supporting trials.

He then made another hypothesis stating, “If I change the mass of the ball so that it decreases then the final kinetic energy decreases. He conducted an experiment and proceeded to the analyze section.  He then formulateed the interpretation, “When I changed the mass of the ball so that it increased the initial kinetic energy decreased”, but provided no supporting trials.
Student One then made his third hypothesis: “If I change the height of the drop so that it decreases then the final kinetic energy doesn’t change”, and ran an experiment. After waiting for 17 seconds (perhaps to read the graphs), he moved on to the analyze section and formed the interpretation “When I changed the mass of the ball so that it increased the final mechanical energy increased” and provided no supporting trials.

Student One then moved on to the hypothesize section but then moved on to the observe section. He then proceeded to run a trial. He then ran a second trial, this time decreasing the height of the ball’s drop. He ran a third trial, this time increasing the drop height. After running trials in the observation section, he moved on to form a new hypothesis: “If I change the mass of the ball so that it decreases then the initial mechanical energy decreases” but did not perform any trials. He formed the interpretation “When I changed the mass of the ball so that it decreased the initial mechanical energy decreased,” providing no supporting trials.

Student One formulated another hypothesis, this time stating, "If I change the mass of the ball so that it decreases then the initial mechanical energy decreases." He moved on to the experiment section and ran one trial before moving on to the analyze section. He formed the interpretation, "When I changed the mass of the ball so that it decreased the initial mechanical energy decreased," providing no supporting trials.

Student One then formulated one last hypothesis, stating, "If I change the mass of the ball so that it decreases then the initial mechanical energy decreases." He went on to the experiment section and performed one trial before moving on to the analyze section. He constructed the interpretation "When I changed the mass of the ball so that it decreased the initial mechanical energy it decreased" without providing any supporting evidence.

### *Embedded Post Assessment*

When asked whether the height of the ball affects the initial potential energy it has, Student One answered "Yes" with "i know this because I experimented it before [sic]" as an explanation. When asked whether the height of the ball affects the final kinetic energy it has, he answered "No" with no explanation. When asked whether the height of the ball affects the amount of mechanical energy it has, he answered "Yes" with "know this because i experimented it before" [sic] as an explanation.

It seems that Student One is not grasping the fundamentals of CVS.  He demonstrates changes in variables but he did not control the variables in response to his created hypotheses, as evidenced by his log files.  Explanations are brief with little thought apparent in their formation; however, most of his analyses and answers to embedded assessments are correct. It seems that he is more focused on the actual simulation of the ball dropping and takes no notice of the charts provided. Luckily, he was able to extrapolate many of the relationships that he previously did not realize. As a result, even though he was clueless to the subject matter before the microworld, he was still able to determine many of the desired concepts.

## Skate Rink Microworld

### *Embedded Pre Assessment*

When asked whether the ball's energy is ever destroyed as it rolls in the rink, Student One answered "No."

### *Skate Ring Activity*

Student One began the activity by creating the hypothesis, "When the ball rolls down the rink the kinetic energy will be transformed into potential energy." He then moved on to the experiment section and ran a trial. After about 9 seconds (perhaps to review the results of the trial), he continued to the analyze section and created the interpretation "When the ball rolled down the rink potential energy was destroyed" without providing any supporting trials.

### *Embedded Post Assessment*

When asked whether the ball's energy is ever destroyed as it rolls in the rink, Student One answered "No" with the explanation of "i know this bcause nothin happened [sic]."

In this microworld, Student One makes inconsistent claims as to the destruction of energy and a short, unobservant answer ("nothing happened") demonstrate a lack of understanding of the subject material.  Here, the student's lack of previous physics knowledge and experience shows; the animation of the ball in the rink and the corresponding concepts of energy transfer were foreign to him. Unfortunately, the advanced level of understanding that the conservation of energy requires is too much for a student with no previous understanding of the concept. Regardless, he answers a number of pre- and post- test questions both correctly and consistently.

### *Content Knowledge Post Test*

In the first section, Student One answered that the apple at rest in a tree had energy in relation to the ground. He answered that the apple has the most mechanical energy right after it starts to fall down, the most potential energy halfway through its fall, and the most kinetic energy right before it reaches the ground.

In the second section, when asked what happens to the ball's potential energy as it falls, Student One answered that some of it is destroyed.

In the third section, Student One answered that for two apples of equal height and mass, one in motion and the other at rest, the one in motion has more kinetic energy, the one at rest has more potential energy, and the one in motion has more mechanical energy.

In the fourth section, Student One answered that for two apples of equal height but different masses; the less massive has more potential energy and the more massive will have more kinetic energy if both fall at the same time.

### Analysis

Student One did not have any prior experience with the concepts of kinetic, potential, and mechanical energy in addition to the conservation of energy. However, he showed a substantial amount of gained understanding from the microworld after its completion (increase of three more questions that were answered correctly out of the eight total pre- and post- test questions and that same increase in embedded questions answered correctly out of the seven total) even though it was not designed to be used as a first level instruction. This likely can be attributed to his numerous amounts of trial runs for each microworld activity. Even though he did not control his variables in the intended manner, he was still able to realize important aspects of the targeted content knowledge.

## Student Two

### About Student

Student Two is a thirteen year old male in the eighth grade. He enjoys math, gym, and lunch the most in school. He enjoys learning science all the time and finds science classes usually easy. His grades in science classes are mostly in the A range and his overall grades are mostly in the A range.

### Dependent/Independent Variable Knowledge

Student Two was not sure about the definition of a dependent variable and fired a scaffold to help him understand. He also was unsure about the definition of an independent variable and fired a scaffold for that as well. After learning about the correct definitions of dependent and independent variables, he answered that his understanding of them was in the middle.

## Content Knowledge Pre Test

In the first section, when asked whether the apple in the tree has energy relative to the ground, Student Two answered that there is not enough information to answer the question. He answered that "the apple always has the same mechanical energy throughout its fall, has the most potential energy at the beginning of its fall and has the most kinetic energy towards the end of its fall".

In the second section, he answered that "more potential energy is created as the apple falls".

In the third section, he answered that "for two apples of equal mass and height, the one at rest has more kinetic and mechanical energy than the one at rest while the one in motion has more potential energy than the one at rest".

In the fourth section, he answered that "for two apples at the same height but different masses, the more massive has more potential energy". Student One also answered that "the more massive apple will have a greater kinetic energy if both fell".

Student Two demonstrates a fair understanding of the principles underlying the energy concepts to be covered in the microworld.  He answered incorrectly to a small number of the pre-test questions, showing an adequate level of knowledge of concepts.

## Freefall Microworld (Mass)

### *Embedded Pre Assessment*

When asked whether the mass of the ball affects the amount of initial potential energy it has, Student Two answered that it does not. When asked whether the mass of the ball affects the amount of final kinetic energy it has, he answered that it does not. Student Two also answered that the mass of the ball does not affect mechanical energy.

### *Freefall Activity*

Student Two began by creating the hypothesis, "If I change the mass of the ball so that it increases then the final potential energy doesn't change" and moved on to experiment. As evidenced in his log files, he ran one trial before proceeding to the analyze section. He then created the interpretation. "When I changed the mass of the ball so that it increased the initial potential energy didn't change" and provided no supporting trials.

### *Embedded Post Assessment*

When asked whether the mass of the ball affects the amount of initial potential energy it has, Student Two answered that it does not with the explanation "i ment to say no but i really didnt know the answer i guessed [sic]." When asked whether the mass of the ball affects the amount of final kinetic energy it has, he answered "Yes" with the explanation "on the ghaph it showed the kinetic energy going up [sic]." When asked whether the mass of the ball affects the mechanical energy it has, he answered "No" with the explanation "in the mechanical energy the mass of the ball doesnt matter thats what the graph shows it's at a consant rate [sic]."

Student Two made incorrect hypotheses and interpretations. He did not run enough trials to properly utilize CVS and even stated that he guessed (incorrectly) at the relation between mass and potential energy. However, it is very interesting to note that when questioned about the kinetic and mechanical energy, Student Two asserts correctly their relationships with the mass of the ball, citing the graphs as specific evidence to support his claim. All this comes after Student Two claimed to have not had any idea about the subject per the embedded pre-assessment questions. It might be interesting to note this direct correlation between the level of active involvement and the amount of understanding gained.

## Freefall Microworld (Height)

### *Embedded Pre Assessment*

When Student Two was asked whether the height of the ball affects the amount of initial potential energy it has, he answered that he does not know. When asked whether the height of the ball affects the amount of final kinetic energy it has, he said he did not know as well. He answered that the height of the ball does not affect mechanical energy when he was asked how the height of the ball affects the amount of mechanical energy it has.

### *Freefall Activity*

Student Two began the activity by creating the hypothesis. “If I change the height of the drop so that it increases then the initial mechanical energy decreases.” He then moved on to the experiment section. He started by decreasing the drop of the ball and ran his first trial. He then increased the mass of the ball and ran the trial again. Student Two then moved on to the analyze section and created the interpretation. “When I changed the height of the drop so that it increased the initial mechanical energy didn’t change,” providing both trials as supporting evidence.

### *Embedded Post Assessment*

When asked whether the height of the ball affects the amount of initial potential energy it has, Student Two answered “Yes” with the explanation. “the height of the ball affects the potential energy by increasing i think thats what the graph was talking about [sic].” When asked whether the height of the ball affected the final kinetic energy of the ball, he answered “Yes” with the explanation “the height of the ball affects the final kinectic energy by decreasing the graph shows [sic].” When asked whether the height of the ball affected the mechanical energy, he answered “No” with the explanation “the graph shows that the mechiancal energy doesnt increase once its at a point it stays constant [sic].”

Once again, Student Two shows no use of CVS in his collection of data through microworld trials, by virtue of there not being enough trials executed in order to compare and contrast resulting data. Student Two also answers a majority of the embedded post-assessment correctly, correctly citing the graphs as evidence to his claims. It seems that, according to his open response answers, he took an invested interest in and reliance on the real-time graphs embedded into the microworlds to a fair degree of success, despite not utilizing proper CVS methodology. This is an important observation considering that a student with rather low involvement can still show improvement if given a stimulating way of looking at information; in this case, the real time graphs.

## Skate Ring Microworld

### *Embedded Pre Assessment*

When Student Two was asked whether the ball's energy is ever destroyed as it rolls in the rink, he answered "No."

### *Skate Ring Activity*

Student Two started the activity with the hypothesis "When the ball rolls down the rink the mechanical energy will stay the same." He then moved on the experiment section and ran a trial. He paused for 23 seconds, perhaps to analyze the charts, before decreasing the size of the rink and increasing the mass of the ball. He ran the trial and moved on to the analyze section. He formed the interpretation "When the ball rolled down the rink kinetic energy was created" without providing supporting trials.

### *Embedded Post Assessment*

When asked whether the ball's energy is ever destroyed as it rolls in the rink, he answered "No" with the explanation "the energy is never destroyed because the ball is always moving [sic]." Here, the failings of not using CVS methodology catch up to Student Two. Only pausing the microworld once, presumably to look at the graphs and then only making one uncontrolled change to the microworld variables, he moves on to correctly answer the post-assessment question, but in his reasoning, his failure to comprehensively grasp the underlying concepts of this microworld are apparent.

### *Content Knowledge Post Test*

In the first section, Student Two answered that the apple does not have energy with relation to the ground. He answered that the apple always has the same mechanical energy throughout its fall. When asked when during its descent it has the most potential, he answered that none of the above choices (right after it starts to fall, halfway, right before it reaches the ground, and the apple always has the same potential energy) were correct. He answered that the apple has the most kinetic energy right after it starts to fall down.

In the second section, Student Two answered that after falling for some distance, some potential energy is destroyed.

In the third section, for two apples at the same height and equal mass with one in motion and the other at rest, Student Two answered that the one in motion has more kinetic energy and both have the same amount of potential and mechanical energy.

In the fourth section, for two apples at equal height but different masses, Student Two answered both have the same potential and kinetic energy.

## Analysis

Student Two shows a marked affinity for the use of the real-time embedded graphs in his data assessment. Most claims that he uses graphs in support of are correct. However, it is clear that he is not familiar with the principles of energy in which these microworlds are based, nor does he utilize proper CVS methods during his running of the trials.

## Student Three

### About Student

Student Three is a thirteen year old male in the $8^{th}$ grade. His favorite subject in school is English. He enjoys learning science sometimes and finds science classes usually easy. His grades in science classes are mostly in the B range with his overall grades being in the B range.

### Dependent/Independent Variable Knowledge

Student Three was unable to identify what a dependent variable is but knew what an independent variable was. When asked how sure he was about the definition for each, he answered that he was a little sure about what he learned.

### Content Knowledge Pre Test

In the first section, Student Three answered that the apple in the tree has energy relative to the ground. Student Three answered that the apple has the most mechanical energy halfway through its fall and the same potential energy throughout its fall. He answered “None of the above” when asked when the mechanical energy is highest during its fall.

In the second section, Student Three answered that during its fall, some of the apple’s potential energy is destroyed.

In the third section, for two apples of equal mass and height with one in motion and the other at rest, both have the same kinetic energy, the one in motion has more potential energy, and the one at rest has more mechanical energy.

In the fourth section, for two apples at equal height but different masses, Student Three answered that the more massive apple has more potential energy and will also have more kinetic energy when both fall.

Student Three is showing glaring inconsistencies in his pre-test content knowledge answers. This is either from a lack of understanding or apathy towards the questions. Such continuity errors are indicative of the latter. Though the last two questions were answered correctly, it is still within the realm of probability for a student who is guessing to get these last questions right.

## Freefall Microworld (Mass)

### *Embedded Pre Assessment*

When asked whether the mass of the ball affects the amount of initial potential energy it has, Student Three answered "No." When asked whether the mass of the ball affects the final kinetic energy it has, he answered "Yes." He answered that as mass decreases mechanical energy decreases when asked how mass affects mechanical energy.

### *Freefall Activity*

Student Three started off the activity by going to the observe section and performing some trials. He first ran a trial without changing any variables. He then increased the drop height and increased the mass of the ball and ran the trial. Next he decreased the drop height and the mass and ran the trial. He then ran the next trial after decreasing the drop height and increasing the mass of the ball. There was a delay before he set up his next trial, perhaps to observe the graph of the last trial. He then increased the mass of the ball and ran another trial. He then decreased the mass of the ball and ran another trial. Lastly, he increased the mass of the ball and ran his last trial in the observe section.

He then moved on to the hypothesis section and formed his hypothesis: “If I change the height of the drop so that it increases then the final kinetic energy increases.” He ran one trial without changing any variables before moving on to the analyze section. He formed the interpretation “When I changed the height of the drop so that it increased the final kinetic energy didn’t change” without providing any supporting trials.

### *Embedded Post Assessment*

When asked whether the mass of the ball affects the amount of initial potential energy it has, Student Three answered “No” with the explanation “you see it does not matter what the mass is it matters what the hight is [sic].” When asked whether the mass of the ball affects the amount of final kinetic energy it has, Student Three answered “No” with the explanation “It doesn’t matter what the mass is it will still have the same kinetic energy [sic].” When asked whether the mass of the ball affects the mechanical energy it has, Student Three answered “I forgot.”

Obviously there is a clear lack of understanding of the concepts present in the microworlds. Every question that was answered in an open format was answered incorrectly and Student Three either demonstrated a clear misunderstanding of the physical laws covered in the microworld simulations, total disassociation with CVS methods or both. Or he forgot the effects of the variables on mechanical energy, despite being able to view the results of the microworld on the same screen that the answers were presented.

## Freefall Microworld (Height)

### *Embedded Pre Assessment*

Student Three answered “Yes” when asked if the height of the ball affects the initial potential energy it has. When he was asked whether the height of the ball affects the final kinetic energy it has, he answered “Yes.” For the question “How does the height of the ball affect the amount of mechanical energy it has?” Student Three answered “As height decreases mechanical energy decreases.”

### *Freefall Activity*

Student Three began by forming the hypothesis “If I change the height of the drop so that it increases, then the final kinetic energy increases.” He moved on to the experiment section and ran one trial before going to the analyze section. He formed the interpretation “When I changed the height of the drop so that it increased the initial potential energy increased” without providing any supporting trials.

### *Embedded Post Assessment*

When Student Three was asked whether the height of the ball affects the initial potential energy, he answered “Yes” and explained “it is the more kintic energy it will have [sic].” When asked whether the height of the ball affects the final kinetic energy, he answered “Yes” and explained “it will have more [sic].” When asked whether the height of the ball affects the mechanical energy it has, he answered “Yes” and explained “it will have less [sic].”

When compared to the last trial, the complete opposite of the previous performance by Student Three is shown. Every single question was answered correctly and open response questions showed that Student Three could defend his findings with reasonable liberties granted. This, like Student Two, proves that the level of gained competence with the subject matter directly correlates to the level of involvement by the student at any given time.

## Skate Ring Microworld

### *Embedded Pre Assessment*

When asked if the ball’s energy is ever destroyed as it rolls down the rink, Student Three answered “Yes.”

### *Skate Ring Activity*

Student Three began by going to the observe section and running a trial before moving on to the hypothesize section and creating the hypothesis “When the ball rolls down the rink kinetic energy will be created.” He did not perform any trials and moved on to the analyze section. He formed the interpretation “When the ball rolled up the rink kinetic energy was created” and did not provide any supporting data.

### *Embedded Post Assessment*

When asked whether the ball’s energy is every destroyed as it rolls down the rink, Student Three answered “Yes” with the explanation “kinetic is when it is physical and potencal is when its not physical [sic].”

Student Three reverts back to an area of misunderstanding with this microworld, flip-flopping between hypotheses and analyses statements without running any trials, clearly not demonstrating CVS, and equating potential energy to a force that is “not physical.” Once again, it appears that the conservation of energy is too difficult a concept for a student that had little to no prior understanding of the material.

## Content Knowledge Post Test

In the first section, Student Three answered that there is not enough information to determine whether the apple has energy relative to the ground. When asked when the falling apple has the most mechanical energy, he answered “None of the above.” He answered that the falling apple has the most potential energy right after it starts to fall down and the most kinetic energy right before it reaches the ground.

In the second section, Student Three answered that after falling for some distance, some potential energy is transformed into kinetic energy.

In the third section, Student Three answered that for two apples of equal mass and height with one at rest and the other in motion, the one in motion has more kinetic energy, both have the same amount of potential energy, and the one on motion has more mechanical energy.

In the fourth section, Student Three answered that for two apples of equal height but different masses, both have the same amount of potential energy and the same amount of kinetic energy if both are falling.

### Analysis

Student Three answers a lot of questions correctly in the post-test assessment, perhaps more than would be probable if only guessing were utilized as the main question answering method. He seems to do quite well with questions pertaining to potential energy and not so well with those having to do with everything else, on a whole. This partial level of improvement very likely stems from the students on and off involvement with the microworld program.

## Student Four

### About Student

Student Four is a thirteen year old female in the seventh grade. She does not have any favorite classes and does not enjoy learning science at all. She finds science class usually easy. Her science grades are usually in the C range and overall her grades are in the B range.

## Dependent/Independent Variable Knowledge

For dependent variable, Student Four did not know its definition. She was unable to identify the correct definition for independent. Student Four answered that she is in the middle on her understanding of the vocabulary.

## Content Knowledge Pre Test

In the first section, when asked whether the apple has energy relative to the ground, Student Four answered "Yes." She answered that, during its descent, the apple has the most mechanical energy right before it reaches the ground, has the same potential energy throughout its fall, and has the most kinetic energy right after it starts to fall down.

In the second section, when Student Four was asked what happens to the potential energy as it falls, she answered that some potential energy is transferred to kinetic energy.

In the third section, for two apples of equal mass and height, one at rest and the other in motion, Student Four answered that the apple at rest has more kinetic energy, the one in motion has more potential energy, and the one at rest has more mechanical energy.

In the fourth section, for two apples at equal height but different masses, both have the same amount of potential energy and the same amount of kinetic energy after falling at the same time.

The results of Student Four's pre-test assessment show little more than the probable results of random guessing. It is clear that she, like the three previous students, had not yet reached a grade level in which kinetic, potential, or mechanical energy is discussed.

## Freefall Microworld (Mass)

### *Embedded Pre Assessment*

When asked whether the mass of the ball affects its initial potential energy, Student Four answered "No." She answered "Yes" when she was asked whether the mass of the ball affects its final kinetic energy. She answered "All of the above" when asked how mass affects the amount of mechanical energy it has.

### *Freefall Activity*

Student Four began her activity with the hypothesis "If I change the height of the drop so that it increases then the initial potential energy increases." She proceeded to the experiment section and increased the mass of the ball. She ran the trial and moved on to the analyze section after about 11 seconds, perhaps to look over the graphs. She then returned to the experiment section and decreased the height of the drop, perhaps realizing that she had changed the wrong variable. She then ran the trial. She then increased the mass of the ball and the height of the ball. She ran the trial and fired the first level of scaffold 2 for not controlling for variable. The message was on the screen for about 14 seconds before she closed it, giving her plenty of time to read the contents of the message. She then moved on to the analyze section after 22 seconds. She formed the interpretation "When I changed the height of the drop so that it increased the initial kinetic energy increased" providing the second trial as supporting evidence.

### *Embedded Post Assessment*

When she was asked whether the mass of the ball affects the initial potential energy it has, she answered “Yes” and explained “just drop the ball and you'll find out [sic].” When she was asked whether the mass of the ball affects the final kinetic energy it has she answered “Yes” with the explanation “go back to school [sic].” When she was asked whether the mass of the ball affects the mechanical energy it has, she answered “DROP THE BALL, MAKE RECORDS AND DO THE MATH [sic].”

Student Four showed no attempt at a CVS strategy while executing the experiments within the microworlds and her results showed the effects of this. Clearly she took little care in the set-up and follow through of the microworld experiments and didn’t bother to put much thought into her answers, electing to utilize sarcastic responses for the open response questions.

## Freefall Microworld (Height)

### *Embedded Pre Assessment*

When asked whether the height of the ball affects the amount of initial potential energy it has, she answered “Yes.” When asked whether the height of the ball affects the amount of final kinetic energy it has, she answered “Yes.” When asked how the height of the ball affects the amount of mechanical energy it has, she answered “As height decreases mechanical energy decreases.”

### *Freefall Activity*

Student Four began her activity creating the hypothesis “If I change the height of the drop so that it decreases then the initial potential energy decreases.” She moved on to the experiment and ran her first trial. She then decreased the height as well as the mass, triggering the first level of scaffold 2 when she runs the trial. She promptly moved on to the analyze section after firing the scaffold. She formed the interpretation “When I changed the height of the drop so that it decreased the initial potential energy increased,” providing the first trial as supporting evidence.

### *Embedded Post Assessment*

When she was asked whether the height of the ball affects the initial potential energy it has, she answered “No” with the explanation “I DONT KNOW [sic].” When asked whether the height of the ball affects the final kinetic energy it has she answered “No” with the explanation “I DONT KNOW [sic].” When she was asked whether the height of the ball affects the mechanical energy it has she answered “Yes” with the explanation “LETS FIND OUT [sic].”

Misunderstandings of the basic underlying concepts required to complete the microworld are again present in this student’s answers. It is clear that she either does not know what she is doing or does not care to put forth any effort in answering these questions. The recurrent open responses of “I DON’T KNOW” on nearly all subjects coupled with her incorrect data interpretation and lack of CVS methods shows that Student Four has not yet learned anything from these microworlds or does not care to apply the knowledge she has.

## Skate Ring Microworld

### *Embedded Pre Assessment*

When Student Four was asked whether the ball's energy is ever destroyed as it rolls in the rink, she answered "Yes."

### *Skate Ring Activity*

Student Four's activity began with building the hypothesis "When the ball rolls up the rink the potential energy will be destroyed." She then moved on to the experiment section and ran a trial. She paused the trial for about 6 seconds and moved on to the analyze section. She formed the interpretation "When the ball rolled down rink kinetic energy was created," and provided no supporting trials.

### *Embedded Post Assessment*

When Student Four was asked whether the ball's energy is ever destroyed as it rolls in the rink, she answered "No" with the explanation "I DONT KNOW [sic]."

Once again, the open response of "I DON'T KNOW" coupled with incorrect answers to the embedded questions and an incorrect hypothesis/interpretation shows Student Four either does not understand the material presented or does not care to demonstrate any proficiency in the material that she may have.  Despite answering the post-assessment question correctly, the open response answer this student provided shows no definite understanding of the topics presented.

### *Content Knowledge Post Test*

In the first section, when Student Four was asked whether the apple has energy relative to the ground, she answered "Yes." She answered that during its fall, the apple has the most mechanical energy halfway through its fall and the most potential energy right after it starts to fall down. She answered "None of the above" when asked when the apple has the most kinetic energy.

In the second section, Student Four answered that after falling for some distance, some of the ball's potential energy is destroyed.

In the third section, Student Four answered that for two apples of equal mass and height with one at rest and the other in motion, the one at rest has more kinetic energy, both have the same amount of potential energy, and the in motion has more mechanical energy.

In the fourth section, Student Four answered that for two apples at equal height but different masses, the more massive apple has more potential energy and both have the same kinetic energy when they fall together.

## Analysis

The glaring inconsistencies in the answers which Student Four provides as well has her consistent open response answers of "I DON'T KNOW" that were more frequent than any other response show a constant lack of understanding of the concepts presented in the microworlds.

Once again, a lack of prior knowledge and a level of apathy for the microworld this student provided on this particular day proved to be highly detrimental to the process.

## Student Five

### About Student

Student Five is a fourteen year old female in the eighth grade. Her favorite subject is English. She does not enjoy learning science at all and finds science classes difficult. Both her science and overall grades are usually in the F range.

### Dependent/Independent Variable Knowledge

Student Five was unable to identify the correct definition of a dependent variable and was able to identify the correct definition of an independent variable. She answered that she is in the middle about being sure about the vocabulary.

### Content Knowledge Pre Test

In the first section, when asked whether the apple had energy relative to the ground, Student Five answered “Yes.” When she was asked “During its descent, when does the apple have the most mechanical energy?” she answered “None of the above.” She answered that the apple has the same potential energy throughout and the most kinetic energy right before it reaches the ground.

In the second section, she answered that after falling for some distance, nothing happens to the potential energy.

In the third section, for two apples of equal height and mass with one in motion and the other at rest, Student Five answered that the one on motion has more kinetic energy, the one in motion has more potential energy, and the one at rest has more mechanical energy.

In the fourth section, for two apples of equal height but different masses, she answered that both have the same amount of potential energy and the less massive will have more kinetic energy when falling.  The results show that Student Five had very little previous understanding of the material.

## Freefall Microworld (Mass)

### *Embedded Pre Assessment*

When asked whether the mass of the ball affects the initial potential energy it has, she answered “I don’t know.” When asked whether the mass of the ball affects the final kinetic energy it has, she answered “No.” When asked how mass affects the mechanical energy of the ball, Student Five answered “As mass decreases mechanical energy decreases.”

### *Freefall Activity*

During the activity, Student Five went to the observer section and ran her first trial. She then ran another trial without changing any variables. She then increased the drop height and ran a third trial. Next, she increased the mass of the ball and ran another trial. She decreased the height and mass of the ball and ran another trial.

She moved on to the hypothesis section and formed the hypothesis “If I change the height of the drop so that it decreases then the initial mechanical energy increases.” She formed a second hypothesis of “If I change the height of the drop so that it decreases then the final potential energy increases.” She moved on to the experiment section and ran one trial before proceeding to the analyze section. She formed the interpretation “When I changed the mass of the ball so that it increased the initial mechanical energy increased” without providing any supporting trials.

### *Embedded Post Assessment*

When asked whether the mass of the ball affects the initial potential energy it has, she said “No” with an explanation of “idk [sic].” When asked whether the mass of the ball affects the final kinetic energy it has, she answered “No” with an explanation of “idk [sic].” When asked whether the mass of the ball affects the mechanical energy it has she answered “Yes” with an explanation of “idk [sic].”

Student Five clearly had very little previous experience with the material. She was also reluctant to properly utilize the hypothesis builder in conjunction with the microworld design. In addition, it appears that she did not use the microworld to enough effectiveness to learn anything from it as shown by the fact that her incorrectly answered embedded post assessment questions were unchanged from her embedded pre assessment questions. Her provided explanations of “idk” show a clear lack of interest.

## Freefall Microworld (Height)

### *Embedded Pre Assessment*

When asked whether the height of the ball affects the initial potential energy it has, Student Five answered “Yes.” When asked whether the height of the ball affects the final kinetic energy it has she answered “No.” When asked how the height of the ball affects the mechanical energy, she answered “All of the above.”

### *Freefall Activity*

For her freefall activity, Student Five first created a hypothesis of “If I change the height of the drop so that it increases then the initial mechanical energy increases.” She then moved on to the experiment section and immediately to the analyze section without performing any trials. She then formed the interpretation “When I changed the height of the drop so that it increased the final mechanical energy didn’t change” without providing any supporting trials.

### *Embedded Post Assessment*

When asked whether the height of the ball affects the initial potential energy it has, she answered “No” with an explanation of “No.” When asked whether the height of the ball affects the final kinetic energy it has, she answered “Yes” with an explanation of “then shes just stupid [sic].” When asked whether the height of the ball affects the mechanical energy it has, she answered “Yes” with an explanation of “like i said that girl is just stupid [sic].”

Again, Student Five shows little previous experience with the material, but is even more evident this time by her sarcastic and trivial answers such as “like i said that girl is just stupid”.  Her microworld activity showed only a lack of interest and motivation to attempt rationalization.

## Skate Ring Microworld

### *Embedded Pre Assessment*

When asked whether the ball’s energy is ever destroyed as it rolls in the rink she answered “Yes.”

### *Skate Ring Activity*

Student Five began her activity by forming the hypothesis “When the ball rolls up the rink the potential energy will stay the same.” She then moved on to the experiment section and then immediately to the analyze section without performing any trials. She formed the interpretation “When the ball rolled up the rink mechanical energy was created” without providing any supporting trials.

### *Embedded Post Assessment*

When she was asked whether the ball’s energy is ever destroyed as it rolls in the rink she answered “Yes” with an explanation of “i dont know [sic].”

Little work is actually done in this activity, with Student Five creating only one hypothesis and performing no trials. This lack of interpretation and collection lead to her inability to correctly answer the embedded post assessment or form a reasonable explanation for her answer.

## Content Knowledge Post Test

In the first section, Student Five answered that the apple has energy relative to the ground. She answered that the apple has the most mechanical energy halfway through its fall, the most potential energy right after it starts to fall down, and the most kinetic energy halfway through its fall.

In the second section, Student Five answered that after falling for some distance, some potential energy is transferred to kinetic energy.

In the third section, for two apples of equal mass and height with one in motion and the other at rest, Student Five answered that the one at rest has more kinetic energy, the one at rest has more potential energy, and the one in motion has more mechanical energy.

In the fourth section, for two apples at equal height but different masses, Student Five answered that the more massive object has more potential energy and the less massive has more kinetic energy when they both fall together.

## Analysis

As shown, it is unlikely that Student Five had any understanding of the material either before or after the microworld design. She was obviously uninterested in the activity and unmotivated to put any effort into actually learning the material. However, it appears from an examination of the pre-post tests (assuming that she did not randomly select answers to complete the task as quickly as possible) that her largest problem was a lack of understanding of the vocabulary. The terms kinetic, potential, and mechanical energy were completely foreign to her. Had she been previously familiar with the material, it is likely that she would have put more effort into the program and possibly have had a positive outcome.

## Student Six

### About Student

Student Six is a sixteen year old female in the ninth grade. Her favorite subjects in school are "gym and everything except for math because I struggle." She enjoys learning science at all times and finds her science classes usually easy. Her science grades are mostly in the C range and her overall grades are mostly in the D range.

### Dependent/Independent Variable Knowledge

When asked what a dependent variable is, she was unable to identify the correct definition. She did, however identify the correct definition for an independent variable. She answered that she was a little sure about the vocabulary.

### Content Knowledge Pre Test

In the first section, Student Six answered that the apple has energy relative to the ground. She answered that during its descent, the apple has the most mechanical energy right before it reaches the ground, has the same potential energy throughout its fall and the most kinetic energy halfway through its fall.

In the second section, Student Six answered that after falling for some distance, some of the ball's potential energy is transferred to kinetic energy.

In the third section, Student Six answered that for two apples of equal mass and height with one at rest and the other in motion, both have the same amount of kinetic, potential, and mechanical energy.

In the fourth section, Student Six answered that for two apples at equal height but different masses, the more massive apple has more potential energy and has more kinetic energy when falling.

Student Six appeared to have at least some level of prior knowledge to the activity. She incorrectly quantified the amounts of kinetic and potential energy in the first several questions (perhaps due to a mix-up of the differences in meanings of kinetic and mechanical energy). However, she did understand the concept of energy transfer.

## Freefall Microworld (Mass)

### *Embedded Pre Assessment*

When asked whether the mass of the ball affects the initial potential energy it has, she answered "Yes." When she was asked whether the mass of the ball affects the final potential energy it has, she answered "Yes." She answered "As mass decreases mechanical energy decreases."

### *Freefall Activity*

Student Six began the activity by creating the hypothesis “If I change the mass of the ball so that it decreases then the initial kinetic energy decreases.” She then moved on to the experiment section and performed one trial. Student Six then proceeded to the analyze section and formed the interpretation “When I changed the mass of the ball so that it decreased the initial kinetic energy decreased,” providing one trial as supporting evidence.

Student Six returned to the hypothesize section and created the hypothesis “If I change the mass of the ball so that it increases then the initial potential energy decreases.” She moved on to the experiment section and ran one trial before proceeding to the analyze section. Student Six then formed the interpretation “When I changed the mass of the ball so that it increased the initial potential energy increased,” providing the last trial as supporting evidence.

### *Embedded Post Assessment*

When asked whether mass of the ball affects the initial potential energy it has, Student Six answered “Yes” with the explanation “if the mass doesn't change no matter what the intial energy will change [sic].” When asked whether the mass of the ball affects the final kinetic energy it has, she answered “Yes” with the explanation “no matter what if the mass of the ball is the same so if the kinetic energy will change [sic].” When asked whether the mass of the ball affects the mechanical energy of the ball, she answered “Yes” with the explanation “if the mass is the same the mechanical energy will change because if the apple hits the ground the mechanical energy will decrease [sic].”

Student Six started off this section correctly answering all pre test questions, suggesting that she might have a good understanding of the concepts. Although she might not have tested her hypotheses correctly or analyzed them thoroughly, she demonstrated her ability to form hypotheses relevant to the pre assessment by making only mass related hypotheses. Her explanations in the post assessment, however, might discredit her correct answers.

## Freefall Microworld (Height)

### *Embedded Pre Assessment*

Student Six answered “Yes” when asked whether the height of the ball affects its initial potential energy. She answered “Yes” when asked whether the height of the ball affects the final kinetic energy. When asked how height affects the mechanical energy of the ball, she answered “As height increases mechanical energy increases.”

### *Freefall Activity*

For the freefall activity, Student Six started off by forming the hypothesis “If I change the height of the drop so that it decreases then the initial kinetic energy decreases.” She moved on to the experiment section. She ran one trial and moved on to the analyze section. She formed the interpretation “When I changed the height of the drop so that it decreased the initial kinetic energy decreased,” providing the one run as supporting evidence.

### *Embedded Post Assessment*

When asked whether the height of the ball affects the initial potential energy it has, she answered "Yes" with the explanation "the height of the ball affects the kinectic energy so as the height decreases the kinetic energy increases [sic]." When asked whether the height of the ball affects the final kinetic energy it has, she answered "Yes" with the explanation "when the height increases the kinetic energy will decrease [sic]." When asked whether the height of the ball affects the mechanical energy it has, she answered "Yes" with "when the height of the ball decreases mechanical energy will increase."

Again, Student Six is able to form relevant hypotheses for this section, this time focusing on height related predictions. However, she continued to fall short of performing enough trials to arrive at any conclusion. Her open response questions are slightly ambiguous but this may be due to the wording of our question; in the first two responses, her answers could be considered correct if one imagines the height changing during the fall, i.e. as the ball falls (height decreases), the kinetic energy increases. Her initial conceptions of the affect of height on an object were most likely reinforced by the activity.

## Skate Ring Microworld

### *Embedded Pre Assessment*

When asked whether the ball's energy is ever destroyed as it rolls down the rink, Student Six answered "No."

### *Skate Ring Activity*

For the skate ring activity, Student Six started off forming the hypothesis “When the ball rolls down the rink the potential energy will be transformed into potential energy.” She moved on to the experiment and ran a trial. She watched the trial run for 10 seconds, perhaps to observe the changes in energy, and paused it. She then proceeded to the analyze section and formed the interpretation “When the ball rolled down the rink potential energy was created” and provided no supporting trials.

### *Embedded Post Assessment*

When asked whether she thinks the ball’s energy is every destroyed as it rolls down the rink, Student Six responded “Yes” with the explanation “potential,kinetic,and mechanical energy are different. [sic]”

Student Six was able to correctly answer the only question in this activity in the pre-test, but the possibility that it was a guess is very apparent from her interaction with the microworld and her change of answer in the post assessment. She did, however, let the trial run for about 10 seconds before pausing it, which suggests that she was observing the trial as it ran. Although her claim in the explanation is correct, it is not exactly relevant to the question at hand.

## Content Knowledge Post Test

In the first section, Student Six answered that the apple does not have energy relative to the ground. She answered that the apple has the most mechanical energy right before it reaches the ground, the most potential energy right before it reaches the ground, and the most kinetic energy right after it starts to fall down.

In the second section, she answered that after falling for some distance, more potential energy is created for the apple.

In the third section, for two apples of equal mass and height with one in motion and the other at rest, Student Six answered that the one in motion has more kinetic energy, the one at rest has more potential energy, and the one in motion has more mechanical energy.

In the fourth section, for two apples at equal height but different masses, Student Six answered that the more massive apple has more potential energy at rest and also has more kinetic energy right before reaching the ground.

### Analysis

Student Six made some noticeable improvements on her post test assessment. She seems to have understood a little more on the different types of energy and the affects of mass and height on the different types. However, the activities might have reversed her previously correct notion of the transfer of energy

## Student Seven

### About Student

Student Seven is a thirteen year old male in the eighth grade. He likes science and math classes the most. He also enjoys learning science all the time and finds science classes usually easy. His science grades are mostly in the A range and his overall classes are mostly also in the A range.

## Dependent/Independent Variable Knowledge

Student Seven answered that he did not know the definition for a dependant variable or an independent variable. After being shown the definitions for each one, he answered that he is a little sure about the vocabulary.

## Content Knowledge Pre Test

In the first section, when asked whether the apple has energy relative to the ground, Student Seven answered “Yes.” He answered that the apple always has the same mechanical, potential and kinetic energy when it falls.

In the second section, Student Seven answered that after the apple has fallen for some distance, nothing happens to the potential energy.

In the third section, he answered that for two apples of equal height and mass with one at rest and the other in motion, both have the same amount of kinetic, potential and mechanical energy. In the fourth section, he answered that for apples of equal height and different masses, both have the same amount of potential energy and both have the same amount of kinetic energy when falling.

Here we can see that Student Seven might not be familiar with the different concepts that will be explored in the following activities.

## Freefall Microworld (Mass)

### *Embedded Pre Assessment*

When asked whether the mass of the ball affects the initial potential energy it has, he answered "No." When asked whether the mass of the ball affects the final kinetic energy it has, he answered "No." Student Seven answered "All of the above" when asked how the mass of the ball affects the mechanical energy it has.

### *Freefall Activity*

For the freefall activity, Student Seven began by forming the hypothesis "If I change the mass of the ball so that it increases then the initial potential energy doesn't change." He then moved on to the experiment section and increased the height of the drop before running his first trial. He then increased the mass of the ball and ran another trial. He then decreased the mass of the ball and runs another trial. In his next trial, he decreased the mass and drop height. As a result, he fired the first level of scaffold 2. He closed the message after 2 seconds. In his next trial, he increased the mass. Next, he increased the mass again and ran another trial. Next, he increased the height of the ball and fired the first level of scaffold 1 when he ran the trial. The message was on the screen for about 4 seconds before he closed it and moved on to the analyze section. He formed the interpretation "When I changed the mass of the ball so that increased the final kinetic energy increased" without providing any supporting trials.

### *Embedded Post Assessment*

When asked whether the mass of the ball affects the initial potential energy it has, he answered "Yes" with the explanation "i incresed or decreased the mass of the ball the amount of initail energy at the begining of the drop the start at higher or lower amounts of energy [sic].” When asked whether the mass of the ball affects the final kinetic energy it has, he answered “Yes” with the explanation “when i incresed or decreased the mass of the ball the amount of final kinetic energy at the begining and end of the drop it stays the same [sic].” When asked whether the mass affects the mechanical energy it has, he answered “Yes.” with the explanation “the higher the mass of the ball was the higher the mechanical energy would go [sic].”

Here we can see how well forming good hypotheses, running trials and well placed scaffolds help a student understand concepts. Student Seven entered this section not knowing much about the affects of mass on the ball’s different energies. However, with enough exploration and the aid of the microworld through scaffolds, he was kept on track resulting in excellent interpretations and explanations for his answers.

## Freefall Microworld (Height)

### *Embedded Pre Assessment*

When asked whether the height of the ball affects the amount of the initial potential energy it has, he answered “No.” When asked whether the height of the ball affects the amount of final kinetic energy it has, he answered “Yes.” When asked how the height of the ball affects the mechanical energy it has, Student Seven answered “All of the above.”

### *Freefall Activity*

To start off the freefall activity, Student Seven formed the hypothesis "If I change the mass of the ball so that it increases then the initial kinetic energy increases." He moved on to the experiment section and ran his first trial. He then increased the mass of the ball and ran another trial. He increased the mass of the ball again and ran a third trial. Afterwards, he moved on to the analyze section and formed the interpretation "When I changed the mass of the ball so that it decreased the initial kinetic energy didn't change" without providing any supporting trials. He also created the interpretation "When I changed the mass of the ball so that it increased the final mechanical energy increased" without providing any supporting trials

### *Embedded Post Assessment*

When asked whether the height of the ball affects the initial potential energy it has, Student Seven answered "Yes" with the explanation "the higher it is the initial potential energy starts at zero [sic]." When asked whether the height of the ball affects the final kinetic energy it has, he answered "Yes" with the explanation "the higher it is the final kinetic energy it has [sic]." When asked whether the height of the ball affects the amount of mechanical energy it has, he answered "Yes" with the explanation "the higher the ball the more mechanical energy it has [sic]."

Student Seven was able to correctly answer and explain his choices in the post assessment, but he did not test for the correct independent variable (height in this case). However, the interpretations he reached were consistent with the hypotheses he made and the trials he ran.

## Skate Ring Microworld

### *Embedded Pre Assessment*

When asked whether the ball's energy is ever destroyed as it rolls in the rink, he answered "No."

### *Skate Ring Activity*

Student Seven's activity started with him forming the hypothesis "When the ball rolls up the rink the potential energy will be destroyed." He moved on to the experiment section and immediately moved on to the analyze section without performing any trials. He formed the interpretation "When the ball rolled down the rink the kinetic energy did not change" without providing any supporting trials.

### *Embedded Post Assessment*

When Student Seven was asked whether the ball's energy is ever destroyed as it rolls in the rink, he answered "No" with the explanation "the energy will lower thn rise again [sic]."

Student Seven appears to have lost interest at this point, judging by the lack of trials run in this activity. However, he correctly answered both the pre and post assessments, with his open response explanation suggesting that he noticed the rising and falling of energy (he does not specify which) during the trial without attributing it to the destruction or creation of energy.

## Content Knowledge Post Test

In the first section, when asked whether the apple has energy relative to the ground, Student Seven answered "Yes." He answered that during its descent the apple has the most mechanical, potential and kinetic energy right after it starts to fall down.

In the second section, Student Seven answered that after falling for some distance, more potential energy is created.

In the third section, Student Seven answered that for two apples of equal mass and height with one in motion and the other at rest, the one in motion has more kinetic energy, the one in motion has more potential energy, and the one at rest has more mechanical energy.

In the fourth section, Student Seven answered that for two apples of different masses, the more massive has more potential energy and the more massive has more kinetic energy when it falls.

## Analysis

Overall, Student Seven made great improvements in almost every section. The scaffolds seem to have played a role in helping his learning experience by providing enough of a push in the right direction to still allow him to observe and learn on his own.

## Student Eight

### About Student

Student Eight is a sixteen year old female in the ninth grade. She enjoys gym and biology classes the most. She enjoys learning science at all times and usually finds her science classes easy. Her science grades are mostly in the B range and her overall grades are mostly in the D range.

### Dependent/Independent Variable Knowledge

Student Eight did not know what a dependent or independent variable is. After being explained what both of them are, she answered that she is in the middle about her understanding of the vocabulary.

### Content Knowledge Pre Test

In the first section, when Student Eight was asked whether the ball has energy relative to the ground, she answered “No.” She answered that during its descent, the ball has the same mechanical energy when it falls, has the most potential energy right after it starts to fall down, and has the most kinetic energy halfway through its fall.

In the second section, Student Eight answered that after falling for some distance, more potential energy is created.

In the third section, Student Eight answered that for two apples of the same mass and height with one in motion and the other at rest, the one at rest has more kinetic energy, the one motion has more potential energy, and both have the same amount of mechanical energy.

In the fourth section, for two apples at equal height and different masses, Student Eight answered that the less massive one has more potential energy and the more massive one has more kinetic energy when falling.

Based on the answers given by Student Eight, we can conclude that she does not have a good understanding of the material covered in the microworlds.

## Freefall Microworld (Mass)

### *Embedded Pre Assessment*

When asked whether the mass of the ball affects the initial potential energy it has, she answered "I don't know." When asked whether the mass of the ball affects the final kinetic energy it has, she answered "Yes." When she was asked how the mass of the ball affects the mechanical energy it has, she answered "If mass decreases, so does the mechanical energy."

### *Freefall Activity*

In the freefall activity, Student Eight formed the hypothesis "If I change the mass of the ball so that it decreases then the initial kinetic energy increases." She formed a second hypothesis stating "If I change the height of the ball so that it decreases then the final kinetic energy will decrease." She ran one trial and moved on to the analysis section. She then moved back to the experiment section, perhaps realizing that she needed more trials. She ran a second trial without changing any variables, thus triggering the first level of scaffold 1. After a short pause, she decreased the elevation and ran another trial. She then increased the height of the ball and ran another trial. She then moved on to the analyzed section and formed the interpretation "When I changed the height of the drop so that it decreased, the initial kinetic energy decreased" without supporting any trials as evidence.

### *Embedded Post Assessment*

In the first section, when asked whether the mass affects the initial potential energy it has, she answered "Yes" with the explanation "if mass of the ball increases then the initial potential energy increases too [sic]." When asked whether the mass of the ball affects the final kinetic energy it has, she answered "Yes" with the explanation "if the mass of the ball increases then the final kinetic energy increases too [sic]." When asked whether the mass of the ball affects the mechanical energy it has, she answered "Yes" with the explanation "if the mass of the ball increases then the mechanical energy increases too [sic]."

Student Eight's post assessment indicates an improvement over the pre assessment. However, her interaction with the microworld shows that she did not test for the affect of mass on the ball; it could be possible that she confused mass with height on either her trials or post assessment responses.

## Freefall Microworld (Height)

### *Embedded Pre Assessment*

When asked whether the height of the ball affects the initial potential energy it has, Student Eight answered “I don’t know.” When asked whether the height of the ball affects the final kinetic energy it has, she answered “I don’t know.” When asked how height affects mechanical energy, she answered “As height decreases, mechanical energy decreases.”

### *Freefall Activity*

During the freefall activity, Student Eight formed the hypothesis “If I change the height of the drop so that it decreases then the initial mechanical energy increases.” She then moved on to the experiment section and ran her first trial. In her second trial she decreased the height of the ball. In her third trial, she increased the height of the ball. In her fourth trial, she increased the mass of the ball, triggering the first level of scaffold 1. She then proceeded to the analyze section and formed the interpretation “When I changed the height of the drop so that it decreased the initial mechanical energy increased” providing the second trial as evidence.

### *Embedded Post Assessment*

When asked whether the height of the ball affects the amount of initial potential energy it has, she answered “Yes” with the explanation “the hieght of the ball increases becouse everything else increases too [sic].” When asked whether the height of the ball affects the amount of final kinetic energy it has, she answered “No” with the explanation “everything decreases [sic].” When asked whether the height of the ball affects the amount of mechanical energy it has, she answered “Yes” with the explanation “idk, [sic].”

It appears that Student Eight's experience with the microworld helped her understand the affect of height on the ball's energy. She was able to form a good hypothesis and test for the right variable for most of the trials. It is evident that she learned that her hypothesis was wrong by forming an interpretation that did not agree with the initial hypothesis while providing supporting evidence. However, she might have had a hard time transferring this knowledge over to her answers and explanations.

## Skate Ring Microworld

### *Embedded Pre Assessment*

When asked whether the ball's energy is ever destroyed as it rolls in the rink, Student Eight answered "Yes."

### *Skate Ring Activity*

During the activity, Student Eight created the hypothesis "When the ball rolls up the rink kinetic energy will be created." She then moved on to the experiment section and immediately to the analyze section without performing any trials. She then formed the interpretation "When the ball rolled down the rink kinetic energy was created" and "When the ball rolled down the rink kinetic energy was created" without providing supporting trials for either.

### *Embedded Post Assessment*

When asked whether the ball's energy is ever destroyed as it rolls in the rink, Student Eight answered "Yes" with the explanation "idk [sic]."

We can see here that Student Eight did not perform any experiments to test her hypothesis and was unable to make any observations about her hypothesis. Because of this, she was unable to correctly answer the post assessment.

## Content Knowledge Post Test

In the first section, Student Eight answered that the apple does not have energy relative to the ground. She answered that the apple, during its descent, has the most mechanical energy halfway through its fall, the same potential energy as it falls, and "None of the above" for when it has the most kinetic energy.

In the second section, Student Eight answered that after falling for some distance, some potential energy is destroyed.

In the third section, Student Eight answered that for two apples of equal mass and height with one in motion and the other at rest, the one at rest has more kinetic energy, the one at rest has more potential energy, and both have the same amount of mechanical energy.

In the fourth section, Student Eight answered that for two apples at the same height but different masses, the more massive has more potential energy and the less massive has more kinetic energy when falling.

## Analysis

The activities do not seem to have made a positive impact on Student Eight's ability to learn the energy concepts presented here. Perhaps her inability to correctly describe the definitions of independent and dependent variables along with her uncertainty of their definitions could have played a part in this.

## Student Nine

### About Student

Student Nine is a fifteen year old male in the ninth grade. His favorite class in school is science and enjoys learning science sometimes. He finds science usually easy and gets mostly B range grades in his science classes. Overall, he mostly gets grades in the D range.

### Dependent/Independent Variable Knowledge

Student Nine was unable to identify the definition of a dependent variable but was able to do so for the definition of an independent. He was very sure of the vocabulary.

### Content Knowledge Pre Test

In the first section, Student Nine answered that there was not enough information to determine whether the apple has energy relative to ground. He answered that during its descent, the apple has the most mechanical energy right after it starts to fall, has the same potential energy throughout its fall, and has the most kinetic energy right before it reaches the ground.

In the second section, Student Nine answered that after falling for some distance, nothing happens to the potential energy.

In the third section, Student Nine answered that for two apples of equal mass and height with one at rest and the other in motion, both have the same amount of kinetic energy, both have the same amount of potential energy, and the apple at rest has more mechanical energy.

In the fourth section, Student Nine answered that for two apples at the same height but different masses, both have the same amount of potential energy and the more massive has more kinetic energy when falling.

Student Nine does not seem to have previous knowledge of the material.

## Freefall Microworld (Mass)

### *Embedded Pre Assessment*

When asked whether the mass of the ball affects the amount of initial potential energy it has, Student Nine answered “No.” When asked whether the mass of the ball affects the amount of final kinetic energy it has, he answered “I don’t know.” When asked how the mass affects the mechanical energy it has, he answered “Mass of the ball does not affect the mechanical energy.”

### *Freefall Activity*

Student Nine’s first hypothesis was “If I change the mass of the ball so that it increases then the final potential energy doesn’t change.” He then moved on to the experiment section and ran his first trial. He then decreased the height of the ball and its mass as well. He then decreased the mass of the ball and ran another trial, triggering the first level of scaffold 1. In his next trial he increased the mass. Next he increased the mass again and ran his last trial. He then moved on to the analyze section and formed the interpretations “When I changed the mass of the ball so that it increased the initial potential energy increased,” When I changed the mass of the ball so that it increased the final kinetic energy increased,” and “When I changed the mass of the ball so that it increased the final mechanical energy increased,” providing no supporting trials for any of them.

### *Embedded Post Assessment*

When asked whether the mass of the ball affects the amount of initial potential energy it has, he answered “Yes” with the explanation “When you change the mass of the ball the initial potential, initial mechanical, final kinetic, and final mechanical energy is increased.” When asked whether the mass of the ball affects the amount of final kinetic energy it has, he answered “Yes” with the explanation “I wouldn’t know how to explain to you the relationship between the mass of the ball and the final kinetic energy it has.” When asked whether the mass of the ball affects the mechanical energy it has, he answered “I wouldn’t know how to explain to you the relationship between the mass of the ball and the mechanical energy that it has.”

Student Nine was able to learn through the microworld activity. He successfully created and tested his hypothesis using multiple trials and controlling for the right variable with the help of the scaffolding system. He was also able to draw excellent conclusions and improve dramatically on his post assessment. Although his interpretations in the microworld were correct, he was able to explain most of his findings in the post assessment.

## Freefall Microworld (Height)

### *Embedded Pre Assessment*

When asked whether the height of the ball affects the initial potential energy it has, Student Nine answered “Yes.” When asked whether the height of the ball affects the amount of final kinetic energy it has, he answered “Yes.” When asked how the height of the ball affects the mechanical energy it has, he answered “As height increases mechanical energy increases.”

### *Freefall Activity*

For the activity, Student Nine first created the hypotheses “If I change the height of the drop so that it increases then the initial potential energy increases,” “If I change the height of the drop so that it increases then the initial mechanical energy increases,” “If I change the height of the drop so that it increases then the final mechanical energy increases,” If I change the height of the drop so that it increases then the final potential energy increases,” and “If I change the height of the drop so that it increases then the final kinetic energy increases.” He then moved on to the experiment section. For his first trial, he decreased the height. He then increased the height on the next trial. He increased the height one more time on his next trial and moved on to the analyze section. He formed the interpretation “When I changed the height of the drop so that it increased the initial potential energy decreased,” providing the first and second trials as supporting evidence. Student Nine then looked at the data, then the hypotheses list, and returned to the analyze section. He then formed the interpretation “When I changed the height of the drop so that it increased the initial kinetic energy increased” without providing any supporting trials. He then formed the interpretation “When I changed the height of the drop so that it increased the final mechanical energy didn’t change” without providing any supporting trials.

### *Embedded Post Assessment*

When asked whether the height of the ball affects the initial potential energy it has, he answered "Yes with the explanation "The Initial potential energy of the ball changes when the height of the ball is altered in a negative way [sic]." When asked whether the height of the ball affects the final kinetic energy it has, he answered "Yes" with the explanation "The final kinetic energy of the ball changes in a positive way when the height of the ball is altered." When asked whether the height of the ball affects the mechanical energy it has, he answered "No" with the explanation "The amount of mechanical energy that the ball has does not change if the height of the ball is changed."

Again, Student Nine formed a good amount of hypotheses and performed a sufficient amount of trials from which to legitimately make interpretations. Because of this, he was able to slightly improve on the post assessment, providing good explanations; unfortunately, most were incorrect.

## Skate Ring Microworld

### *Embedded Pre Assessment*

When asked whether the ball's energy is ever destroyed as it rolls in the rink, Student Nine answered "No."

### *Skate Ring Activity*

In the skate ring activity, Student Nine created the hypotheses "When the ball rolls down the rink the potential energy will be transformed into mechanical energy," "When the ball rolls down the rink kinetic energy will be created," and "When the ball rolls down the rink mechanical energy will be created." He then moved on to the experiment section, looked at the hypothesis list and ran his first trial. He recorded the current data, paused it, and ran a second trial. He then looked at the data table, looked at the hypothesis list again and moved on to the analyze section. Student Nine then formed the hypothesis "When the ball rolled down the rink mechanical energy did not change" and provided no supporting trials. He then formed the interpretation "When the ball rolled down the rink potential energy was transformed into kinetic energy" and provided no supporting trials. He then formed his last interpretation: "When the ball rolled up the rink kinetic energy was transformed into potential energy" and provided no supporting trials.

### *Embedded Post Assessment*

When asked whether the ball's energy is ever destroyed as it rolls in the rink, Student Nine answered "No" with the explanation "When the ball rolls down the ramp it is transformed from potential energy into kinetic energy and when it is rolling up the ramp it is transformed from kinetic energy into potential energy. Throughout all of this the mechanical energy is not changed [sic]."

Student Nine's ability to observe is clearly evident in his interpretations and explanation in the post test assessment. He was able to form solid hypotheses and test for them explicitly. With this, he drew valid conclusions and arrived at a correct answer.

## Content Knowledge Post Test

In the first section, when asked whether the ball has energy in relation to the ground, Student Nine answered "No." Student Nine answered that as the apple descends, the mechanical energy always is always the same, the most potential energy is right after it starts to fall down, and has the most kinetic energy halfway through its fall.

In the second section, Student Nine answered that after falling for some distance, some potential energy is transferred to kinetic energy.

In the third section, Student Nine answered that for two apples of equal mass and height with one in motion and the other at rest, both have the same kinetic energy, the one in motion has more potential energy, and both have the same amount of mechanical energy.

In the fourth section, Student Nine answered that for two apples at the same height but different masses, both have the same amount of potential energy and both have the same amount of kinetic energy when they fall.

## Analysis

Although Student Nine did very well on the individual microworlds and their corresponding, it seems like the knowledge gained from each one did not transfer over very well in the post content knowledge test. This could be attributed to the length of the entire assessment.

## Student Ten

### About Student

Student Ten is a twelve year old in the seventh grade. His favorite subject in school is math. He enjoys learning science all the time and usually finds science classes easy. His science grades are mostly in the A range and his overall classes are also mostly in the A range.

### Dependent/Independent Variable Knowledge

Student Ten was able to choose the correct definition for a dependent variable but was unable to do so for the definition of an independent variable. He answered that he was in the middle about his understanding of the vocabulary.

### Content Knowledge Pre Test

In the first section, Student Ten answered that the apple has energy relative to the ground. He answered that during the apple's descent, it has the most mechanical energy halfway through its fall, the most potential energy halfway through its fall, and the most kinetic energy halfway through its fall.

In the second section, Student Ten answered that after falling for some distance, potential energy is destroyed.

In the third section, Student Ten answered that for two apples of equal height and mass with one in motion and the other at rest, the one in motion has more kinetic energy, the one in motion has more potential energy, and the one in motion has more mechanical energy.

In the fourth section, Student Ten answered that for two apples at equal height but different masses, the more massive has more potential energy and the less massive has more kinetic energy when falling.

Student Ten seems to have a good handle on the questions covered in the third section but overall seems to be new to the topics covered later.

## Freefall Microworld (Mass)

### *Embedded Pre Assessment*

When asked whether the mass of the ball affects the initial potential energy it has, Student Ten answered "I don't know." When asked whether the mass of the ball affects the final kinetic energy it has, he answered "I don't know." When asked how the mass of the ball affects the mechanical energy it has, he answered "Mass of the ball does not affect mechanical energy."

### *Freefall Activity*

Student Ten's starts the activity by forming the hypothesis "If I change the mass of the ball so that it decreases then the initial kinetic energy decreases." He then proceeded to the experiment section and immediately looks at the hypothesis list, perhaps to remind himself of how he should perform his experiments. He then increases the height of the drop and runs the trial. He then moved on to the analyze section and formed the interpretation “When I changed the mass of the ball so that it decreased, the initial kinetic energy decreased” without providing and supporting trials.

### *Embedded Post Assessment*

When asked whether the mass of the ball affects the amount of initial potential energy it has, Student Ten answered “No” with the explanation “mass of the ball decreases why it falls to the grond [sic].” When asked whether the  mass of the ball affects the amount of final kinetic energy it has, Student Ten answered “No” with the explanation “because it doesnt it fall fast [sic].” When asked whether the mass of the ball affects the mechanical energy it has, he answered “Yes” with the explanation “yes because when it fell form the tree it gets faster [sic].”

It appears that Student Ten still does not have a good understanding of the concepts covered in this microworld. During the microworld he formed a hypothesis that was inconsistent with the questions asked in the pre assessment. He also did not perform enough trials to reach a legitimate interpretation. Because of this, he was unable to correctly answer any of the post assessment questions or provide good explanations for them.

## Freefall Microworld (Height)

### *Embedded Pre Assessment*

When asked whether the height of the ball affects the amount of initial potential energy it has, Student Ten answered “I don’t know.” When asked whether the height of the ball affects the final kinetic energy it has, he answered “Yes.” When asked how the height affects the mechanical energy it has, he answered “All of the above.”

### *Freefall Activity*

In the freefall activity, Student Ten started off by creating the hypothesis “If I change the height of the drop so that it increases then the initial potential energy increases.” He then takes a look at the hypothesis look again, perhaps to look over his hypothesis and then runs a trial. He then moves on to the analyze section and forms the interpretation “When I changed the height of the drop so that it increased the initial potential energy increased” and provides no supporting trials.

### *Embedded Post Assessment*

When asked whether the height of the ball affects the initial potential energy it has, Student Ten answered “No” with the explanation “it gos faster [sic].” When asked whether the height of the ball affects the amount of final kinetic energy it has, he answered “No” with the explanation “it gos faster [sic].” When asked whether the height of the ball affects the amount of mechanical energy it has, he answered “Yes” with an explanation “yes because it gos down faster [sic].”

Again, his lack of hypotheses and trials prevented Student Ten from getting good data and reaching valid conclusions. Because of this, he was unable to correctly answer most of the post assessment questions or provide good explanations.

## Skate Ring Microworld

### *Embedded Pre Assessment*

When asked whether the ball's energy is ever destroyed as it rolls in the rink, Student Ten answered "Yes."

### *Skate Ring Activity*

Student Ten first forms the hypothesis "When the ball rolls down the rink mechanical energy will be destroyed." He goes on to the experiment section and runs his first trial. He goes on to the analyze section after 18 seconds, perhaps to analyze the results of the first trial. He forms the interpretation "When the ball rolled down the rink kinetic energy was destroyed."

### *Embedded Post Assessment*

When asked whether the ball's energy is ever destroyed as it rolls in the rink, Student Ten answers "Yes" with the explanation "it gos it changings [sic]."

Student Ten is again unable to correctly answer this post assessment question. This can once again be attributed to his lack of trials, preventing him from making good observations and drawing conclusions. However, the time spent between running the trial and proceeding to the analyze section might suggest that he did in fact take the time to observe the trial. It could be possible that Student Ten misinterpreted the decreasing kinetic energy bar as the destruction of energy.

### Content Knowledge Post Test

In the first section, Student Ten answered that the apples does have energy relative to the ground. When asked when, during its descent, does the apple have the most mechanical energy, he answered "None of the above." His answer was the same when asked when, during its descent, does the apple have the most potential energy. When asked when, during its descent does the apple have the most kinetic energy, he answered that it always has the same kinetic energy.

In the second section, Student Ten answered that after falling for some distance, some of the apple's potential energy is destroyed.

In the third section, Student Ten answered that for two apples of the same mass and height with one in motion and the other at rest, the one in motion has more kinetic energy, the one at rest has more potential energy, and both have the same amount of mechanical energy.

In the fourth section, Student Ten answered that for two apples of equal height but different masses, the less massive has more potential energy and the more massive has more kinetic energy when it falls.

### Analysis

Again, Student Ten was unable to score well on the content knowledge post test most likely due to the lack of hypotheses made and trials performed in each activity.

## Conclusions

Determining the important assessment from the data is troublesome. Quantitative analysis on this data set is not feasible because of the small sample size, but log files provide rich data about students' inquiry processes. It was unfortunate that many of the students in our sample set were unmotivated to properly perform the microworld activity that we created. Of course, only the students who did engage in the activity would provide useful assessment information.

A good example of a student who provided "good" assessment data is Student Three. His pre test scores were markedly low and he showed large gaps in prior knowledge relating to kinetic, potential, and mechanical energy in addition to transfer of energy, as measured by his pre-test. However, through the use of multiple trials and hypothesis testing, Student Three was able to increase his post test score by 23 percent (Appendix I). This suggests that his level of understanding of the concepts increased by conducting inquiry with our microworlds.

This pattern was repeated in other students as well. For example, Student Seven (2 out of 8 on the pre-test vs. 4 out of 8 on the post-test) also utilized the program effectively and was able to increase his pre to post test score by 19 percent. Students One and Four had increases in scores between the pre- and post-testing stages despite their lower persistence as evidenced by fewer trials. Student One had similar effectiveness with his trial runs in the microworld regardless of his lack of CVS. His score increased by 23 percent. These positive outcomes show that, when used properly by the student, large gains in understanding can be made as well as provide a more detailed picture of the student's understanding of the material than traditional multiple-choice standardized testing strategies.

## Implications of the Testing Environment

It is important to note that our study was intended and designed as a pilot study. The results and findings of our ASSISTments pilot study will inform the continual development of the Science ASSISTments system. Unfortunately, our pilot data for this first stage of production was unreliable. The students did not seem to attend to the scaffolding prompts that were designed to support their experimentation with the microworld, as evidenced by not running enough trials or by not using the advice given. This also may be due to some of the students in our test group not taking the program seriously. Many of them decided to rush through it as fast as they could in order to be done with it. Earlier during the day of testing, the students in our group had taken state-mandated standardized tests in their science classes. These tests, as most standardized test happen to be, were, by students' accounts, excruciatingly boring. It is unfortunate that many of the subjects in our group interpreted our program as "another standardized test" that was forced upon them the same day as the state tests. It is possible that the students in our group were cognitively overloaded and could not engage deeply enough in order to yield data about the efficacy of the activity as an assessment. As a result, our pre and post testing was littered with guessed answers and the microworlds were under-utilized, for example, experimentation within the microworlds was in general either rushed such that most of the students did not complete enough trials to cause scaffolds to fire.

## Implications for Future Development

The problems associated with testing cannot be considered the only issue at hand and the activity can be improved. The most beneficial improvement would likely be a retooled vocabulary section. Our students had shown insufficient prior knowledge of the physical concepts under investigation. As the pre test results demonstrate, a lack of understanding of the terms caused significant problems for most of the students. By adding terms like kinetic, potential, and mechanical energy to the vocabulary section, the students may be given the necessary background to the terms presented to them later on.

In addition to the supplementation of the vocabulary section, it is evident that the microworld activity needs to be made more interesting and stimulating. The main problem with the testing stemmed from a severe lack of interest apparent in the test subjects. They had just spent the entire day taking state-mandated standardized testing and found the microworld to be another unnecessary test (in their eyes) forced upon them. If the program were to be made more interactive and enticing, the students' attention would be far more focused. Similarly, the program should be retooled to have a more streamlined testing approach in order to hold each student's attention more firmly. These problems, above all others, would have greatly influenced our test subjects in a positive manner. For future work, the above changes are necessary to create an assessment that can elicit deep engagement on the part of the students.

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# Appendices

## Appendix A Massachusetts Curriculum Frameworks

***Physical Sciences** **<u>(Chemistry and Physics)</u>***

The physical sciences (chemistry and physics) examine the physical world around us. Using the methods of the physical sciences, students learn about the composition, structure, properties, and reactions of matter, and the relationships between matter and energy.

Students are best able to build understanding of the physical sciences through hands-on exploration of the physical world. This *Framework* encourages repeated and increasingly sophisticated experiences that help students understand properties of matter, chemical reactions, forces and motion, and energy. The links between these concrete experiences and more abstract knowledge and representations are forged gradually. Over the course of their schooling, students develop more inclusive and generalizable explanations about physical and chemical interactions.

Tools play a key role in the study of the physical world, helping students to detect physical phenomena that are beyond the range of their senses. By using well-designed instruments and computer-based technologies, students can better explore physical phenomena in ways that support greater conceptual understanding.

- **In grades PreK-2,** students' curiosity is engaged when they observe physical processes and sort objects by different criteria. During these activities, students learn basic concepts about how things are alike or different. As they push, pull, and transform objects by acting upon them, the students see the results of their actions and begin to understand how part of their world works. They continue to build understanding by telling stories about what they did and what they found out.

Learning standards for PreK-2 fall under the following three subtopics: *Observable Properties of Objects; States of Matter;* and *Position and Motion of Objects.*

- **In grades** 3-5, students' growth in their understanding of ordinary things allows them to make the intellectual connections necessary to understand how the physical world works. Students are able to design simple comparative tests, carry out the tests, collect and record data, analyze results, and communicate their findings to others.

Learning standards for grades 3-5 fall under the following three subtopics: *Properties of Objects and Materials; States of Matter;* and *Forms of Energy* (including electrical, magnetic, sound, and light).

- **In grades 6-8,** students still need concrete, physical-world experiences to help them develop concepts associated with motion, mass, volume, and energy. As they learn to make accurate measurements using a variety of instruments, their experiments become more quantitative and their physical models more precise. Students in these grades are able to graph one measurement in relation to another, such as temperature change over time. They may collect data by using microcomputer- or calculator-based laboratories (MBL or CBL), and can learn to make sense immediately of graphical and other abstract representations essential to scientific understanding.

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Learning standards for grades 6-8 fall under the following five subtopics: *Properties of Matter; Elements, Compounds, and Mixtures; Motion of Objects; Forms of Energy;* and *Heat Energy.*

• **In high school Chemistry,** students learn about the properties of matter and how these properties help to organize elements on the periodic table. Students develop a better understanding of the structure of the atom. Students develop an understanding of chemical reactions, including the involvement of energy and sub-atomic particles, to better understand the nature of chemical changes. Students learn about chemical reactions that occur around us everyday as they learn about chemical reactions such as oxidation-reduction, combustion, and decomposition. Students also gain a deeper understanding of acids and bases, rates of reactions, and factors that affect those rates. From calculating stoichiometry problems and molar concentrations, students learn about proportionality and strengthen their mathematical skills.

Learning standards for high school Chemistry fall under the following eight subtopics: *Properties of Matter; Atomic Structure and Nuclear Chemistry; Periodicity; Chemical Bonding; Chemical Reactions and Stoichiometry; States of Matter, Kinetic Molecular Theory, and Thermochemistry; Solutions, Rates of Reaction, and Equilibrium;* and *Acids and Bases and Oxidation-Reduction Reactions.*

• **In high school Introductory Physics,** students recognize the nature and scope of physics, including its relationship to the other sciences. Students learn about basic topics such as motion, forces, energy, heat, waves, electricity, and magnetism. They learn about natural phenomena by using physical laws to calculate quantities such as velocity, acceleration, momentum, and energy.

Students of introductory physics learn about the relationships between motion and forces through Newton's laws of motion. They study the difference between vector and scalar quantities and learn how to solve basic problems involving these quantities. Students learn about conservation of energy and momentum and how these are applied to everyday situations. They learn about heat and how thermal energy is transferred throughout the different phases of matter. Students extend their knowledge of waves and how they carry energy. Students gain a better understanding of electric current, voltage, and resistance by learning about Ohm's law. They also gain knowledge about the electromagnetic spectrum in terms of wavelength and frequency.

Learning standards for high school Introductory Physics fall under the following six subtopics: *Motion and Forces; Conservation of Energy and Momentum; Heat and Heat Transfer; Waves; Electromagnetism;* and *Electromagnetic Radiation.*

Physical Science learning standards are also grouped under Broad Topics in Appendix I, which highlights the relationships of standards among grade spans.

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***Physical Sciences (Chemistry and Physics), Grades PreK-2***

| *learning standard* | *ideas for developing investigations and learning experiences* | *suggested extensions to learninc in technology/engineering* |
|---|---|---|

*(Technology/Engineering Standards for qrades PreK-2 are on page 85)*

***Observable Properties of Objects***

| | | |
|---|---|---|
| ***1. Sort objects by observable properties such as size, shape, color, weight, and texture.*** | *Manipulate, observe, compare, describe, and group objects found in the classroom, on the playground, and at home.* | Predict from looking at the shape of a simple tool or object what actions it might be used for (e.g., pliers, letter opener, paperweight). (T/E 1.2, 2.1) |

***States of Matter***

| | | |
|---|---|---|
| ***2. Identify objects and materials as solid, liquid, or gas. Recognize that solids have a definite shape and that liquids and gases take the shape of their container.*** | *Using transparent containers of very different shapes (e.g., cylinder, cone, cube) pour water from one container into another. Observe and discuss the "changing shape" of the water.* | Ask students to bring in different types of containers from home. Discuss and demonstrate whether the containers are appropriate to hold solids and liquids (e.g., an unwaxed cardboard box will absorb water and eventually disintegrate while a glass bottle will not). (T/E 1.1, 1.2) |

***Position and Motion of Objects***

| | | |
|---|---|---|
| ***3. Describe the various ways that objects can move, such as in a straight line,* zigzag, *back-and-forth, round-and-round, fast, and slow.*** | *Use a spinning toy (e.g., a top) to explore round-and-round motion and a rocking toy (e.g., a rocking horse) to explore back-and-forth motion.* | Using construction paper and glue, design a three-dimensional object that will roll in a straight line and a three-dimensional object that will roll around in a circle. (T/E 1.3, 2.1) |
| ***4. Demonstrate that the way to change the motion of an object is to apply a force (give it a push or a pull). The greater the force, the greater the change in the motion of the object.*** | *Push and pull objects on a hard, smooth surface. Make predictions as to what directions they will move and how far they will go. Repeat using various surfaces (e.g., rough, soft).* | |
| ***5. Recognize that under some conditions, objects can be balanced.*** | *Try to make a long thin rectangular block of wood stand upright on each face. Note that it stands (balances) very easily on some faces, but not on all.* | Design a lever, putting unequal weights on the ends of the balance board. Observe. Now find ways to restore the balance by moving the fulcrum, keeping each weight in the someplace. Discuss what happens. (T/E 2.1) |

***63*** **Massachusetts Science and Technology/Engineering Curriculum Framework, October 2006**

**Physical Sciences (Chemistry and Physics), Grades 3-5**

| learning standard | ideas for developing investigations and learning experiences | suggested extensions to learning in technology/engineering |
|---|---|---|

**Properties of Objects and Materials**

| | | |
|---|---|---|
| **1. Differentiate between properties of objects (e.g., size, shape, weight) and properties of materials (e.g., color, texture, hardness).** | Gather a variety of solid objects. Collect data on properties of these objects, such as origin (human-made or natural), weight (heavy, | medium, light), length, odor, color, hardness, and flexibility. |

| | | |
|---|---|---|
| *Given a variety of objects made of different materials, ask questions and make* | *predictions about the hardness, flexibility, and strength of each. Test to see if* | *the predictions were correct. (T/E 1.1)* |

**States of Matter**

| | | |
|---|---|---|
| **2. Compare and contrast solids, liquids, and gases based on the basic properties of each of these states of matter.** | Design several stations, each of which demonstrates a state of matter (e.g., water table, balloon and fan table, sand and block table). | *Design one container for each state of matter, taking into account which material properties are important (e.g., size, shape, flexibility). (T/E 1.1, 2.3)* |
| **3. Describe how water can be changed from one state to another by adding or taking away heat.** | Do simple investigations to observe evaporation, condensation, freezing, and melting. Confirm that water expands upon freezing. | *Using given insulating materials, try to keep an ice cube from melting. (T/E 1.1)* |

**Forms of Energy**

| | | |
|---|---|---|
| **4. Identify the basic forms of energy (light, sound, heat, electrical, and magnetic). Recognize that energy is the ability to cause motion or create change.** | Play music through a speaker with and without a grill cover. Discuss the differences in sound. | *Design and construct a candle wheel that demonstrates how heat can cause a propeller to spin.*<br>*(T/E 1.1, 1.2,2.2,2.3)* |
| **5. Give examples of how energy can be transferred from one form to another.** | Rub two pieces of wood together (mechanical energy) and observe the change in temperature of the wood. | *Design and build a simple roller coaster for a marble or toy car to demonstrate how energy changes from one form to another.*<br>*(T/E 2.2, 2.3)* |





| ***learning standard*** | ***ideas for developing investigations and learning experiences*** | ***suggested extensions to learning in technology/engineering*** |
|---|---|---|

| | | |
|---|---|---|
| *Electrical Energy* | | |
| *6. Recognize that electricity in circuits requires a complete loop through which an electrical current can pass, and that electricity can produce light, heat, and sound.* | | • ***Using graphic symbols, draw and label a simple electric circuit. (T/E 2.2)***<br>• ***Using batteries, bulbs, and wires, build a series'circuit. (T/E 1.2,2.2)*** |
| *7. Identify and classify objects and materials that conduct electricity and objects and materials that are insulators of electricity.* | ***Provide a collection of materials that are good conductors and good insulators. Have students determine each material's electrical conductivity by testing the material with a simple battery/bulb circuit.*** | **Select from a variety of materials (e.g., cloth, cardboard, Styrofoam, plastic) to design and construct a simple device (prototype) that could be used as an insulator. Do a simple test of its effectiveness. (T/E 1.1, 1.2, 2.2, 2.3)** |
| *8. Explain how electromagnets can be made, and give examples of how they can be used.* | | **Make an electromagnet with a six-volt battery, insulated wire, and a large nail. (T/E 1.2, 2.1, 2.2, 2.3)** |
| *Magnetic Energy* | | |
| *9. Recognize that magnets have poles that repel and attract each other.* | ***Balance ring magnets on a pencil. Note: The shape of a ring magnet obscures the locations of its poles.*** | **Design and build a magnetic device to sort steel from aluminum materials for recycling. (T/E 1.1)** |
| *10. Identify and classify objects and materials that a magnet will attract and* | *objects and materials that a magnet will not attract.* | |

| | |
|---|---|
| ***Test a variety of materials with assorted magnets. Include samples of pure iron, magnetic steel, and non-magnetic metals in the materials tested. Mention*** | ***the two other magnetic metals: pure cobalt and pure nickel. Test a U.S. five-cent coin to answer the question "Is a U.S. nickel coin made of pure nickel?"*** |

***65*** **Massachusetts Science and Technology/Engineer ing Curriculum Framework, October 2006**

**Physical Sciences (Chemistry and Physics), Grades 3-5**

| learning standard | ideas for developing investigations and learning experiences | suggested extensions to learninc in technology/engineering |
|---|---|---|
| **Sound Energy** | | |
| **11. Recognize that sound is produced by vibrating objects and requires a medium through which to travel. Relate the rate of vibration to the pitch of the sound.** | Use tuning forks to demonstrate the relationship between vibration and sound. | *Design and construct a simple telephone (prototype) using a variety of materials (e.g., paper cups, string, tin cans, wire). Determine which prototype works best and why. (T/E1.1, 1.2, 2.2, 2.3)* |
| **Light Energy** | | |
| **12. Recognize that light travels in a straight line until it strikes an object or travels from one medium to another, and that light can be reflected, refracted, and absorbed.** | Use a flashlight, mirrors, and water to demonstrate reflection and refraction. | *Design and build a prototype to inhibit solar heating of a car (e.g., windshield reflector, window tinting). (T/E 1.2, 2.1, 2.3)* |

**66** ***Massachusetts Science and Technology/Engineering Curriculum Framework, October 2006***

***Physical Sciences (Chemistry and Physics), Grades 6-8***

| *learning standard* | *ideas for developing investigations and learning experiences* |
|---|---|

***Properties of Matter***

***1. Differentiate between weight and mass, recognizing that weight is the amount of gravitational pull on an object.***

*Determine the weight of a dense object in air and in water. Explain how the results are related to the different definitions of mass and weight.*

***2. Differentiate between volume and mass. Define density.***

***3. Recognize that the measurement of volume and mass requires understanding of the sensitivity of measurement tools (e.g., rulers, graduated cylinders, balances) and knowledge and appropriate use of significant digits.***

*Calculate the volumes of regular objects from linear measurements. Measure the volumes of the same objects by displacement of water. Use the metric system. Discuss the accuracy limits of these procedures and how these limits explain any observed differences between the calculated volumes and the measured volumes.*

***4. Explain and give examples of how mass is conserved in a closed system.***

*Melt, dissolve, and precipitate various substances to observe examples of the conservation of mass.*

***Elements, Compounds, and Mixtures***

***5. Recognize that there are more than 100 elements that combine in a multitude of ways to produce compounds that make up all of the living and nonliving things that we encounter.***

*Demonstrate with atomic models (e.g., ball and stick) how atoms can combine in a large number of ways. Explain why the number of combinations is large, but still limited. Also use the models to demonstrate the conservation of mass in the modeled chemical reactions.*

***6. Differentiate between an atom (the smallest unit of an element that maintains the characteristics of that element) and a molecule (the smallest unit of a compound that maintains the characteristics of that compound).***

*Use atomic models (or Lego blocks, assigning colors to various atoms) to build molecules of water, sodium chloride, carbon dioxide, ammonia, etc.*

***7. Give basic examples of elements and compounds.***

*Heat sugar in a crucible with an inverted funnel over it. Observe carbon residue and water vapor in the funnel as evidence of the breakdown of components. Continue heating the carbon residue to show that carbon residue does not decompose. Safety note: sugar melts at a very high temperature and can cause serious bur*

*8. Differentiate between mixtures and pure substances.*



<u>**Physical Sciences (Chemistry and Physics), Grades 6-8**</u>

| learn.ng standard | IDEAS FOR developing iNVESTIGATIONS aND lEARNING eXPERIENCES |
|---|---|
| **Elements, Compounds, and Mixtures (cent.)** | |
| 9. Recognize that a substance (element or compound) has a melting point and a boiling point, both of which are independent of the amount of the sample. | |
| 10. Differentiate between physical changes and chemical changes. | Demonstrate with molecular ball-and-stick models the physical change that converts liquid water into ice. Also demonstrate with molecular ball-and-stick models the chemical change that converts [illegible] |
| **Motion of Objects** | |
| 11. Explain and give examples of how the motion of an object can be described by its position, direction of motion, and speed. | |
| 12. Graph and interpret distance vs. time graphs for constant speed. | |
| **Forms of Energy** | |
| 13. Differentiate between potential and kinetic energy. Identify situations where kinetic energy is transformed into potential energy and vice versa. | |
| **Heat Energy** | |
| 14. Recognize that heat is a form of energy and that temperature change results from adding or taking away heat from a system. | |

| | |
|---|---|
| **15. Explain the effect of heat on particle motion through a description of what happens to particles during a change in phase.** | |
| **16. Give examples of how heat moves in predictable ways, moving from warmer objects to cooler ones until they reach equilibrium.** | **Place a thermometer in a ball of clay and place this in an insulated cup filled with hot water. Record the temperature every minute. Then remove the thermometer and ball of clay and place them in an insulated cup of cold water that contains a second thermometer. Observe and record the changes in temperature on both thermometers. Explain the observations in terms of heat flow, including** |

# Appendix B: Vocabulary

## *B. 1 Energy Vocab introduction*

**Assistment #82450 "82450 - Energy Vocab Introduction"**

**Hello!** You are going to be a scientist today and conduct experiments in a virtual laboratory environment!

Before we do that, we want to make sure you understand the terms and vocabulary used in our scientific experiments. We want to make sure you know about these things:

* A manipulated variable / independent variable
* A responding variable / dependent variable

If you know what these are, great! If you don't know what all of these are, don't worry, it's ok! You will learn shortly.

**Multiple choice:**

✓ OK! I'm ready to learn!

## B. 2 Responding Variable Definition

**Assistment #77707 "77707 - Responding Variable Definition"**

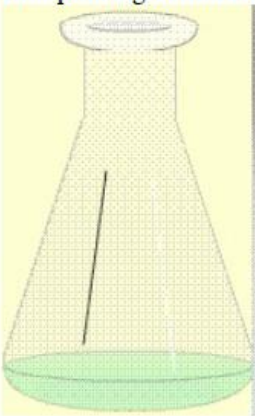
What is a responding variable or dependent variable?

**Multiple choice:**

- ✗ It is any factor that can change in an experiment.
- ✗ It is a factor that you change in an experiment.
- ✓ It is a factor you measure or observe.
- ✗ It is a factor that always stays the same in an experiment.
- ✗ I don't know.

**Scaffold:**

A responding variable or dependent variable is a variable that is measured or observed.




For example, you might conduct an experiment to test if adding salt to water lowers the temperature at which the water freezes. Here, the temperature at which the water freezes is a responding variable because it is a factor you measure.

**Multiple choice:**

- ✓ OK, I understand what a responding variable is.

**Scaffold:**

Now, try again.

What is a responding variable or dependent variable?

**Multiple choice:**

- ✗ It is any factor that can change in an experiment.

  | No, that is a variable in general, not a responding variable. |
  |---|

- ✗ It is a factor that you change in an experiment.

  | No, that is a manipulated variable or independent variable. |
  |---|

- ✓ It is a factor you measure or observe.
- ✗ It is a factor that always stays the same in an experiment.

  | A responding variable may or may not stay the same since it is what you measure in an experiment. |
  |---|

### *B. 3 Manipulated Variable Definition*

**Assistment #77706 "77706 - Manipulated Variable Definition"**

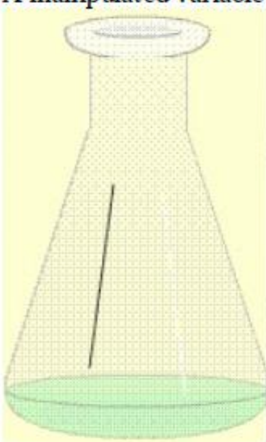
What is a manipulated variable or independent variable?

**Multiple choice:**

- ✗ It is any factor that can change in an experiment.
- ✓ It is a factor that you change in an experiment.
- ✗ It is a factor you measure or observe.
- ✗ It is a factor that always stays the same in an experiment.
- ✗ I don't know.

**Scaffold:**

A manipulated variable or independent variable is a variable that you change in an experiment.




For example, you might conduct an experiment to test if adding salt to water lowers the temperature at which the water freezes. Here, the salt is a manipulated variable because it is a factor you change to conduct the test.

**Multiple choice:**

- ✓ OK, I understand what a manipulated variable is.

**Scaffold:**

Now, try again.

What is a manipulated variable or independent variable?

**Multiple choice:**

- ✗ It is any factor that can change in an experiment.

  No, that is a variable in general, not a manipulated variable.
- ✓ It is a factor that you change in an experiment.
- ✗ It is a factor you measure or observe.

  No, that is a responding variable or dependent variable.
- ✗ It is a factor that always stays the same in an experiment.

  No, a manipulated variable is a variable you change in an experiment.

## *Appendix B. 4 Energy Vocab Conclusion*

**Assistment #82454 "82454 - Energy Vocab Conclusion"**

**A)** 

Great job! Now you're ready to do some experiments since you've learned some of the words and concepts.

Remember:

* A **manipulated variable / independent variable** is a factor that you change in an experiment.

* A **responding variable / dependent variable** is a factor you measure or observe.

**Multiple choice:**

✓ OK! I've read everything above.

**B)** How sure are you about understanding the vocabulary?

Please be honest since we want to improve these instructions if they are not helpful.

**Multiple choice:**

✓ 1. Very sure

✓ 2. A little sure

✓ 3. In the middle

✓ 4. A little unsure

✓ 5. Very unsure

## Appendix C Energy Microworld Pre/Post Test

### *C. 1 Pretest Apple Dropping*

**Assistment #82646 "82646 - Pretest Apple Dropping"**

A) Now we are going to ask some questions related to the energy that an object has.

An apple is hanging from a tree. Does it have energy in relation to the ground?

**Multiple choice:**

- ✓ Yes
- ✗ No
- ✗ There is not enough information to answer the question

B) Shortly after, the apple falls down from the tree. As the apple falls, when does it have the most mechanical energy?

**Multiple choice:**

- ✗ Right after it starts to fall down
- ✗ Halfway

- ✗ Right before it reaches the ground
- ✓ The apple always has the same mechanical energy
- ✗ None of the above

C) During the descent, when does the apple have the most potential energy?

**Multiple choice:**

- ✓ Right after it starts to fall down
- ✗ Halfway
- ✗ Right before it reaches the ground
- ✗ The apple always has the same potential energy
- ✗ None of the above

D) When, during its descent, does the apple have the most kinetic energy?

**Multiple choice:**

- ✗ Right after it starts to fall down
- ✗ Halfway
- ✓ Right before it reaches the ground
- ✗ The apple always has the same kinetic energy
- ✗ None of the above

*C. 2 Pretest Apple Dropping 2*

**Assistment #81828 "81828 - Pretest Apple Dropping 2"**

Use the image below to answer the following questions.

After falling some distance, what happens to the apple's potential energy?

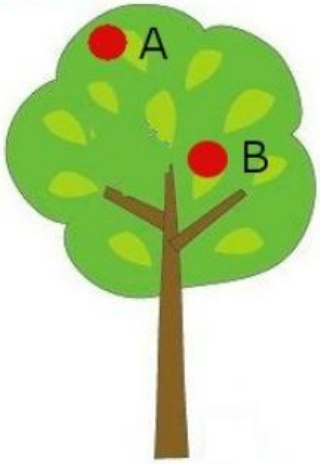
**Multiple choice:**

- ✗ Some of it is destroyed
- ✓ Some of it is transferred to kinetic energy
- ✗ Nothing happens to the potential energy
- ✗ More potential energy is created

## *C. 3 Pretest Apple Dropping 3*

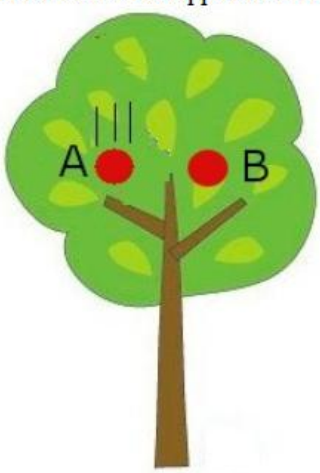
**Assistment #83693 "83693 - Pretest Apple Dropping 3"**

**A)** Now we will look at two apples with equal mass. Apple A is at a higher branch than apple B *(See Picture 1)*.




***Picture 1***

Apple A starts to fall and reaches the height of apple B, which has not yet fallen *(See Picture 2)*. Which of the two apples has more kinetic energy?




***Picture 2***

**Multiple choice:**

- ✓ Apple A
- ✗ Apple B
- ✗ They both have the same amount of kinetic energy

**B)** In the second picture, which apple has the most potential energy?

**Multiple choice:**

- ✗ Apple A
- ✗ Apple B

✘ Right before it reaches the ground

✔ The apple always has the same mechanical energy

✘ None of the above

C) During the descent, when does the apple have the most potential energy?

**Multiple choice:**

✔ Right after it starts to fall down

✘ Halfway

✘ Right before it reaches the ground

✘ The apple always has the same potential energy

✘ None of the above

D) When, during its descent, does the apple have the most kinetic energy?

**Multiple choice:**

✘ Right after it starts to fall down

✘ Halfway

✔ Right before it reaches the ground

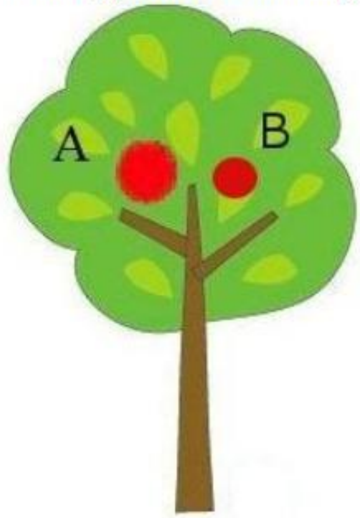
✘ The apple always has the same kinetic energy

✘ None of the above

### *C. 4 Pretest Apple Dropping 4*

**Assistment #83809 "83809 - Pretest Apple Dropping 4"**

**A)** Now we will look at two apples at the same height but with different masses. Apple A has more




mass than apple B.
Which apple has more potential energy?

**Multiple choice:**

- ✓ Apple A
- ✗ Apple B
- ✗ They both have the same amount of potential energy

**B)** Both apples fall from the tree. Right before they reach the ground, which one has more kinetic energy?

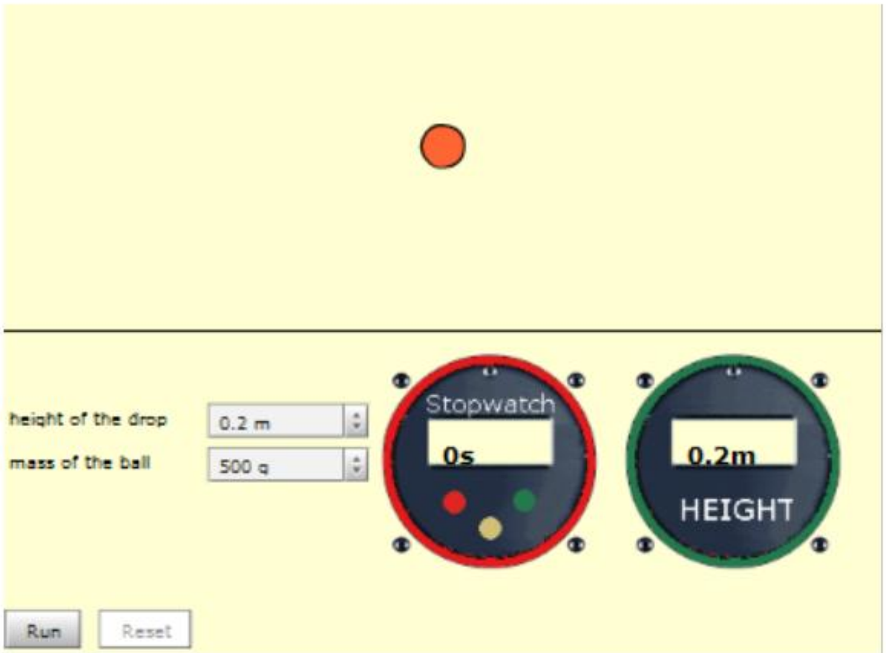
**Multiple choice:**

- ✓ Apple A
- ✗ Apple B
- ✗ They both have the same amount of kinetic energy

## Appendix D Microworld 1 (Mass Exploration)

**Assistment #84630 "84630 - FreeFall PE->KE Microworlds (Mass)"**

A) In this microworld you can change the **height** and **mass** of a ball falling to the ground. Take a minute to explore before you answer the next set of questions which will be related to this microworld.




Now that you've played with our microworld, do you think the mass of the ball affects the amount of initial potential energy it has?

**Multiple choice:**

- ✓ Yes
- ✗ No
- ✗ I don't know

B) Do you think the mass of the ball affects the amount of final kinetic energy it has?

**Multiple choice:**

- ✓ Yes
- ✗ No
- ✗ I don't know

C) How does mass the of the ball affect the amount of mechanical energy it has?

**Multiple choice:**

- ✗ As mass increases mechanical energy increases.
- ✗ As mass decreases mechanical energy decreases.
- ✓ All of the above
- ✗ Mass of the ball does not affect mechanical energy.

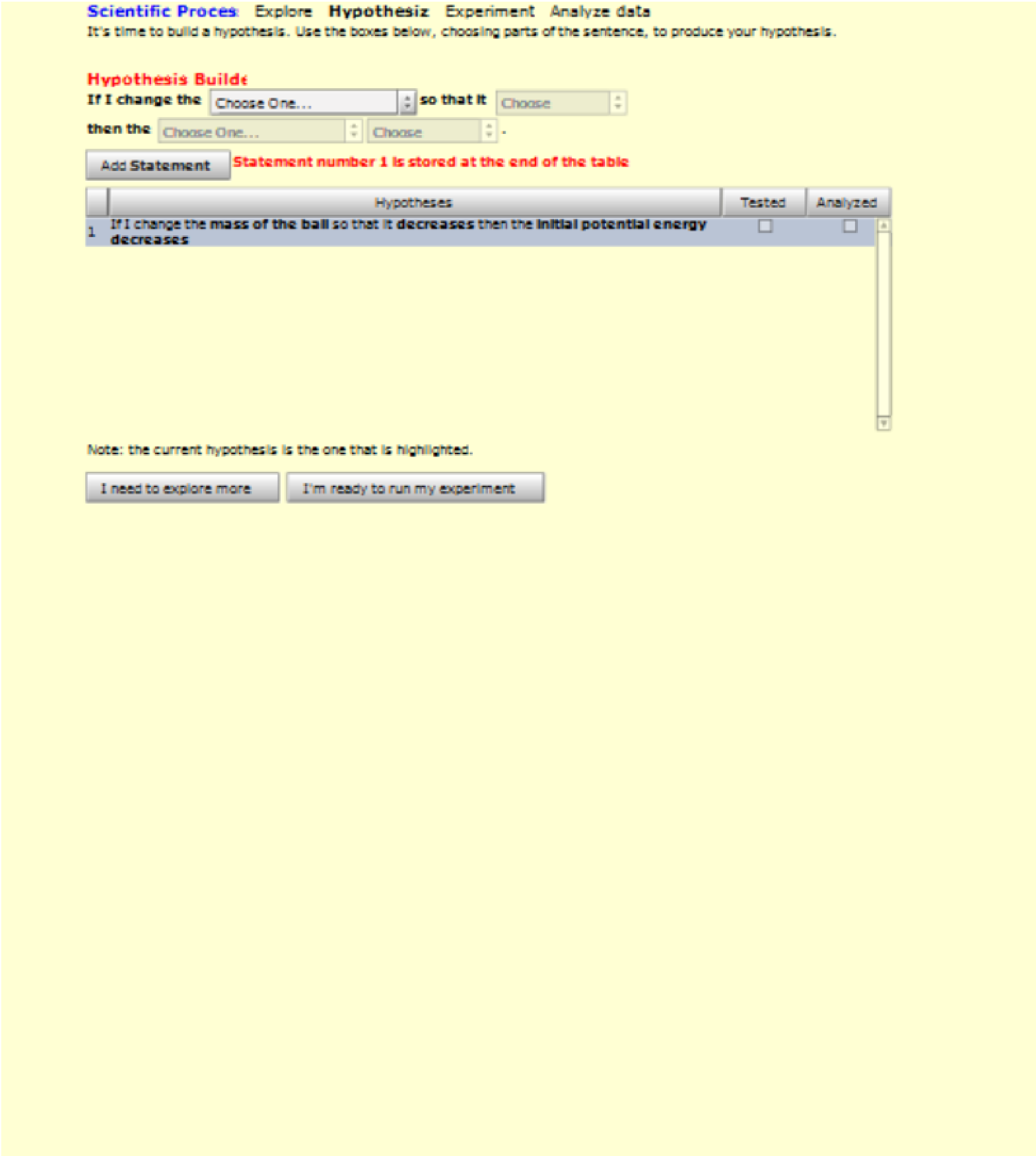
**D)** Now, conduct some experiments to test your above predictions and explore the **relationships between mass and three formss of energy: kinetic, potential and mechanical energy.**

The following steps will help you conduct your experiment:

**1. Hypothesize:** First use the hypothesizing tool to plan your experiments and list your hypotheses.

**2. Collect data to test your hypotheses:** Run as many trials as you need to test your hypotheses.Click the **"Show Table"** Button to see your trials.

**3. Remember to control for variables while collecting data:** Control for variables is when you run a trial in which you change the independent variable (the one you want to manipulate) while keeping all the other variables the same.




**Processed externally (e.g., by a Flash object or Java applet):**

E) Does the mass of the ball affect the initial potential energy it has?

**Multiple choice:**

✓ Yes

✗ No

F) Explain your answer as if you were writing to a friend that doesn't know anything about the relationship between the mass of the ball and the initial potential energy it has.

**Ungraded open response:**

G) Does the mass of the ball affect the final kinetic energy it has?

**Multiple choice:**

✓ Yes

✗ No

H) Explain your answer as if you were writing to a friend that doesn't know anything about the relationship between the mass of the ball and the final kinetic energy it has.

**Ungraded open response:**

I) Does the mass of the ball affect the amount of mechanical energy it has?

**Multiple choice:**

✓ Yes

✗ No

J) Explain your answer as if you were writing to a friend that doesn't know anything about the relationship between mass of the ball and the amount of mechanical energy it has.

**Ungraded open response:**

## Appendix E Microworld 1 (Height Exploration)

**Assistment #84631 "84631 - FreeFall PE->KE Microworlds (Height)"**

**A)** Do you think the height of the ball affects the amount of initial potential energy it has?

**Multiple choice:**

- ✓ Yes
- ✗ No
- ✗ I don't know

**B)** Do you think the height of the ball affects the amount of final kinetic energy it has?

**Multiple choice:**

- ✓ Yes
- ✗ No
- ✗ I don't know

**C)** How does the height of the ball affect the amount of mechanical energy it has?

**Multiple choice:**

- ✗ As height increases mechanical energy increases.
- ✗ As height decreases mechanical energy decreases.
- ✓ All of the above
- ✗ The height of the ball does not affect mechanical energy.

**D)** Now, conduct some experiments to test your above predictions and explore the **relationships between height and kinetic, potential and mechanical energy.**

The following steps will help you conduct your experiment:

**1. Hypothesize:** First use the hypothesizing tool to plan your experiments and list your hypotheses.

**2. Collect data to test your hypotheses:** Run as many trials as you need to test your hypotheses.Click the **"Show Table"** Button to see your trials.

**3. Remember to control for variables while collecting data:** Control for variables is when you run a trial in which you change the independent variable (the one you want to manipulate) while keeping all the other variables the same.


**Processed externally (e.g., by a Flash object or Java applet):**

**E)** Does the height of the ball affect the initial potential energy it has?

**Multiple choice:**

- ✓ Yes
- ✗ No

**F)** Pretend you have a friend who doesn't know anything about the relationship between the height of the ball and the initial potential energy it has. Explain your answer in a way that your friend will

understand.
**Ungraded open response:**

G) Does the height of the ball affect the final kinetic energy it has?
**Multiple choice:**
✓ Yes
✗ No

H) Pretend your friend also doesn't know the relationship between height of the ball and the final kinetic energy it has. Explain your answer in a way that your friend will understand.
**Ungraded open response:**

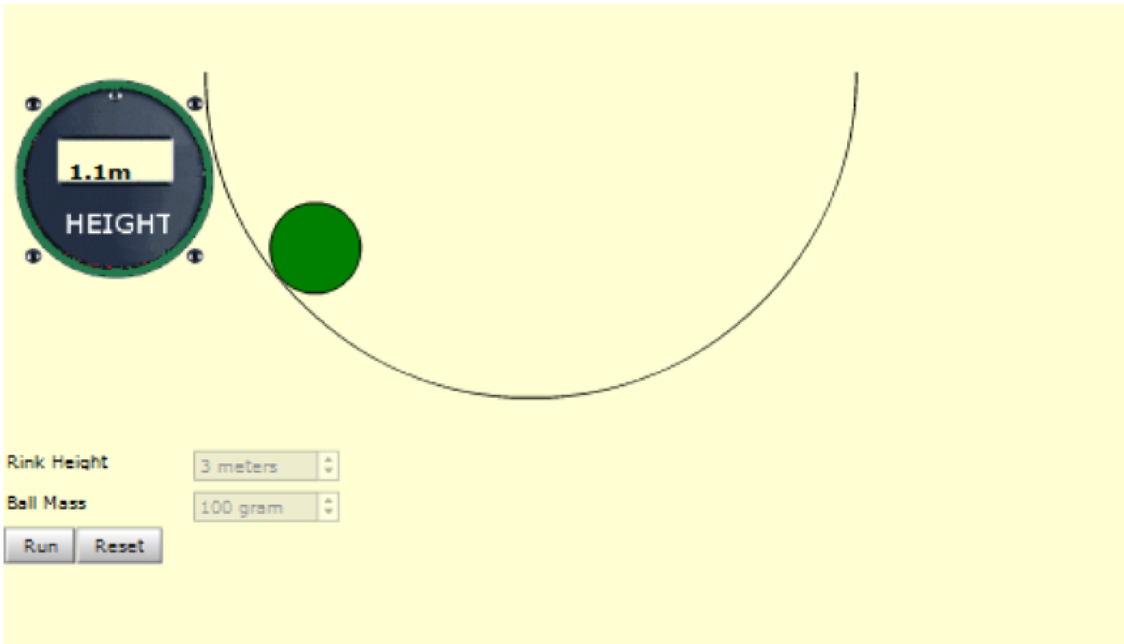
I) Does the height of the ball affect the amount of mechanical energy it has?
**Multiple choice:**
✓ Yes
✗ No

J) Pretend your friend also doesn't know the relationship between height of the ball and the amount of mechanical energy it has. Explain your answer in a way that your friend will understand.
**Ungraded open response:**

# Appendix F Skating Ring Explore

**Assistment #84632 "84632 - 84632 Skate Rink Explore"**

In this microworld you can change the **height of the skate rink** and **mass** of a ball falling to the ground. Take a minute to explore before you answer the next set of questions which will be related to this microworld.




**Multiple choice:**

✓ Ok, I understand

## Appendix G Microworld 2 (Conservation of Energy)

**Assistment #84629 "84629 - SkateRingPE->KE Microworlds (All energies)"**

**A)** Do you think the ball's energy is ever destroyed as it rolls in the rink?

**Multiple choice:**

✘ Yes

✓ No

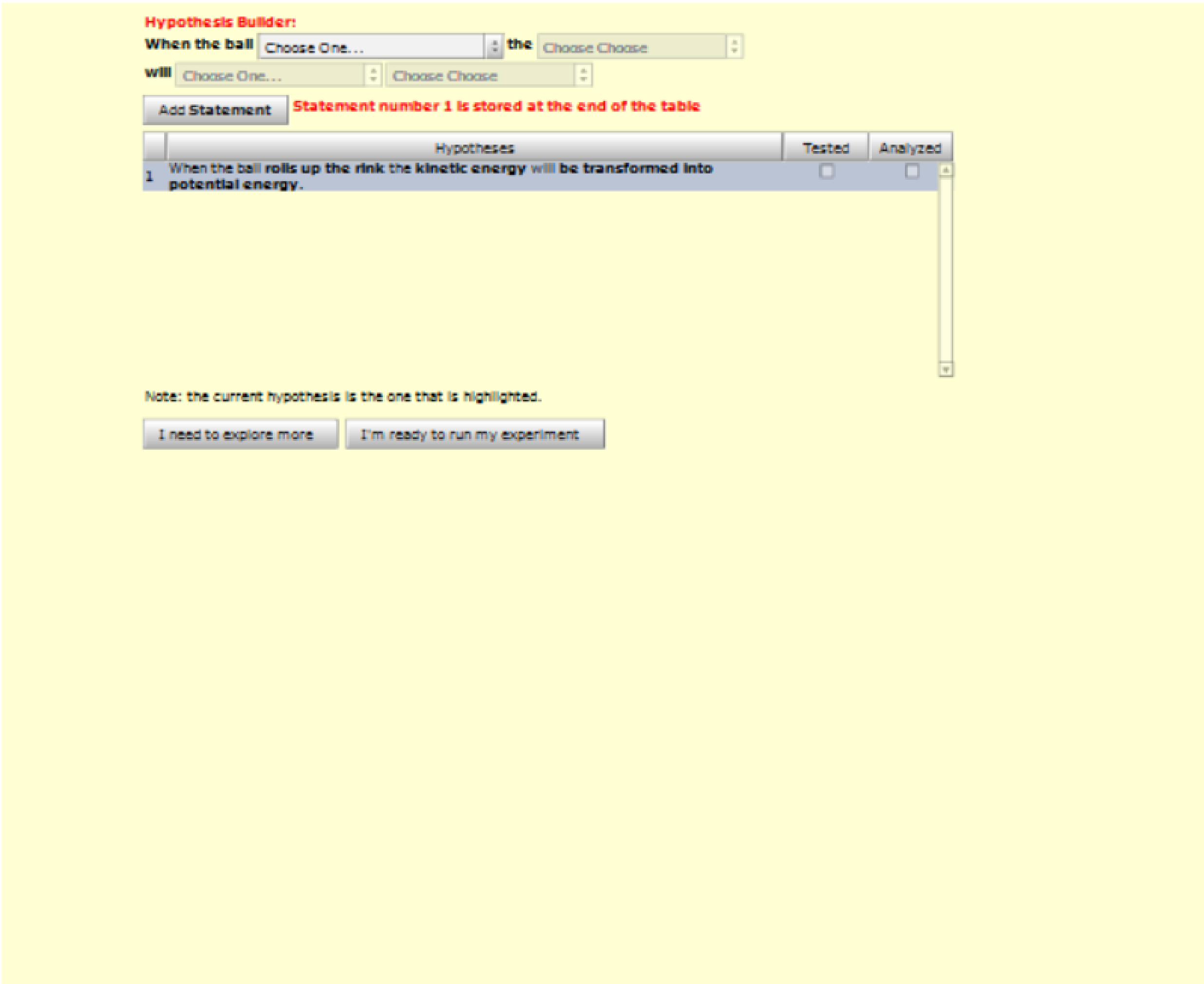
**B) Now conduct some experiments to determine what happens to kinetic, potential, and mechanical energy as the ball rolls in the rink.**

The following steps will help you conduct your experiment:

1. **Hypothesize**: First use the hypothesizing tool to plan your experiments and list your hypotheses.

2. **Collect data to test your hypotheses**: Press the "RUN" button. While the experiment is running you can press the **"Record"** button to save the energy data of each ball at a specific position. You can also pause the ball and then press record. To see your data click the **"Show Table"** button.

3. **Remember to control for variables while collecting data**: Control for variables is when you run a trial in which you change the independent variable (the one you want to manipulate) while keeping all the other variables the same.




**Processed externally (e.g., by a Flash object or Java applet):**

C) During the continuous movement of the ball, is energy ever destroyed?

**Multiple choice:**

✘ Yes

✓ No

D) Please explain your answer as if you were explaining it to a friend that doesn't know anything about potential, kinetic and mechancal energy.

**Ungraded open response:**

## Appendix H Post tests

In order to compare how the students understand has changed over the course of the microworlds the post test was given that was the same as the pretest. Our goal was to test if their core understanding of the concept has changed and maybe they can answer these questions better then the first time they saw them in the pretest.

## Appendix I: Raw Data

This is the raw data gathered automatically from the ASSISTments website and manually from the output of the microworlds.

| Student | Pre Test 1 | Pre Test 2 | Pre Test 3 | Pre Test 4 | Post Test 1 | Post Test 2 | Post Test 3 | Post Test 4 | Gain |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 25% | 0% | 0% | 50% | 50% | 0% | 67% | 50% | 23% |
| 2 | 75% | 0% | 0% | 100% | 25% | 0% | 67% | 0% | -21% |
| 3 | 25% | 0% | 0% | 100% | 50% | 100% | 67% | 0% | 23% |
| 4 | 25% | 100% | 0% | 0% | 50% | 0% | 67% | 50% | 10% |
| 5 | 50% | 0% | 67% | 0% | 25% | 100% | 33% | 50% | 23% |
| 6 | 25% | 100% | 33% | 100% | 0% | 0% | 67% | 100% | -23% |
| 7 | 50% | 0% | 33% | 0% | 25% | 0% | 33% | 100% | 19% |
| 8 | 50% | 0% | 0% | 50% | 0% | 0% | 0% | 50% | -13% |
| 9 | 25% | 0% | 33% | 50% | 50% | 100% | 0% | 0% | 10% |
| 10 | 25% | 0% | 67% | 50% | 25% | 0% | 33% | 50% | -8% |

| **Student** | **Freefall (Mass) Embedded Pre Assessment** | **Scaffolds** | **Trials** | **Time Spent Reading Scaffold (sec)** | **Analyze After Scaffold?** | **Freefall (Mass) Embedded Post Assessment** |
|---|---|---|---|---|---|---|
| 1 | 0% | 1a | 3 | 3 | No | 33% |
| 2 | 0% | | 1 | | | 1 |
| 3 | 33% | | 8 | | | 0% |
| 4 | 67% | 2a | 3 | 14 | Yes | 67% |
| 5 | 0% | | 6 | | | 33% |
| 6 | 67% | | 2 | | | 100% |
| 7 | 33% | 2a, 1a | 7 | 1,0 | No, Yes | 100% |
| 8 | 33% | 1a | 4 | 3 | No | 100% |
| 9 | 0% | 1a | 6 | 8 | No | 1 |
| 10 | 0% | | 1 | | | 33% |

| Student | Freefall (Mass) Embedded Pre Assessment | Scaffolds | Trials | Time Spent Reading Scaffold (sec) | Analyze After Scaffold? | Freefall (Mass) Embedded Post Assessment |
|---|---|---|---|---|---|---|
| 1 | 0% | 1a | 3 | 3 | No | 33% |
| 2 | 0% | | 1 | | | 1 |
| 3 | 33% | | 8 | | | 0% |
| 4 | 67% | 2a | 3 | 14 | Yes | 67% |
| 5 | 0% | | 6 | | | 33% |
| 6 | 67% | | 2 | | | 100% |
| 7 | 33% | 2a, 1a | 7 | 1,0 | No, Yes | 100% |
| 8 | 33% | 1a | 4 | 3 | No | 100% |
| 9 | 0% | 1a | 6 | 8 | No | 1 |
| 10 | 0% | | 1 | | | 33% |

| Student | Freefall (Mass) Embedded Pre Assessment | Scaffolds | Trials | Time Spent Reading Scaffold (sec) | Analyze After Scaffold? | Freefall (Mass) Embedded Post Assessment |
|---|---|---|---|---|---|---|
| 1 | 0% | 1a | 3 | 3 | No | 33% |
| 2 | 0% | | 1 | | | 1 |
| 3 | 33% | | 8 | | | 0% |
| 4 | 67% | 2a | 3 | 14 | Yes | 67% |
| 5 | 0% | | 6 | | | 33% |
| 6 | 67% | | 2 | | | 100% |
| 7 | 33% | 2a, 1a | 7 | 1,0 | No, Yes | 100% |
| 8 | 33% | 1a | 4 | 3 | No | 100% |
| 9 | 0% | 1a | 6 | 8 | No | 1 |
| 10 | 0% | | 1 | | | 33% |