March 2010

Developing and Testing a Density Microworld

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RESEARCH REPORT

Science ASSISTments: Developing and pilot testing middle school students' inquiry skills using a microworld for Density

An Interactive Qualifying Project Report

Submitted to the Faculty

of the

Worcester Polytechnic Institute

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

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March 2010

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Abstract

This paper outlines a design study conducted in an after-school program setting with middle-school aged children in an urban district in the North Eastern United States in order to: 1) design a microworld for Density in order to deepen students' content knowledge of Density, 2) design a set of content knowledge items to assess and characterize students' prior knowledge with regard to density, 3) characterize their inquiry skills before using the microworld, and 4) characterize their inquiry processes via their log files generated as they work within the microworld.

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Introduction

For the 21st century workplace, students need to understand science more deeply, and possess well-honed learning strategies that will allow them to apply their science knowledge in more flexible ways. This is particularly important because American students continue to fall behind their peers from other developed countries (www.pisa.oecd.org/dataoecd/15/13/39725224.pdf).

The National frameworks for science emphasize inquiry skills (National Science Education Standards, NRC, 1996) and claim that these skills are critical to science reform efforts. However, in typical classroom practice, science learning is often focused on rote learning of vocabulary, facts, and formulas because rote knowledge is what is prioritized on high-stakes tests, and science process skills are difficult to assess (Fadel, Honey, & Pasnick, 2007). Hands on, i.e., performance assessments, are more authentic because they require specific skills to solve real problems (Baxter and Shavelson 1994; Ruiz-Primo & Shavelson, 1996), however, these are seldom used in schools, largely due to the difficulty of reliable administration and the resulting high cost. Another critical issue is that since these skills are *developed* in rich scientific contexts, it is crucial that they also be assessed within the contexts in which they are learned and embedded (Mislevy et al., 2002).

Teaching and tutoring students on science process skills is an effective way to acquire both science process skills and transfer these to learn new science content. In order to assess students' inquiry skills, what is needed is frequent, fine-grained performance assessment of students' science process skills so that tutoring can be honed to students' individual needs as they learn within a rich scientific content domain. The Science Assistments project (Gobert et al, 2007; Gobert et al, 2009), described next, is working towards National reform efforts (NSES, 1989).

The Science ASSISTments Program

WPI's Science ASSISTments project directed by Dr. Janice Gobert deals with the design and development of a learning environment and set of virtual microworlds that allow students to hone science content knowledge through the processes of scientific inquiry. The underlying presupposition of the ASSISTments project is that engaging students in scientific inquiry processes via microworlds will positively affect students' scientific skills and, in turn, their scientific content knowledge. The program tutors and assesses middle school students in scientific skills, such as prediction- and hypothesis-making, experimenting with interactive microworlds, collecting and interpreting data, mathematizing data, and defending and communicating scientific claims.

The inquiry experiments require students to utilize the control for variables strategy. The control for variables strategy (CVS) is a domain-general strategy for designing and conducting experiments. CVS is a method for designing experiments in which a single contrast is made between different experimental conditions (Chen & Klahr, 1999) while the other independent variables are held constant. Sao Pedro, Gobert, Heffernan, and Beck (2009) argue in their study that this strategy provides a good conceptual and procedural anchor for students in learning inquiry skills. It is important for students to understand the different variables used in experimentation and how to manipulate these variables, especially independently of each other, as they believe that it is the cornerstone of scientific experimentation. Furthermore, research has shown that this skill does not develop naturally (Kuhn, 2005), and is important to scientific literacy.

Not only are the microworld-based experiments hypothesized to help students gain knowledge of inquiry skills and scientific concepts through a step-by-step inquiry and tutoring processes, they also allow teachers to review assessment reports on the work their students have done. After the students have finished a microworld-based assessment, the teacher can use the information gathered in the reports to determine how well their students scored both in terms of inquiry skills (broken down into 5-6 skills) as well as content knowledge. Therefore, by looking at a series of student trials in a specific content area, teachers can assess a student's progress. As such, the ASSISTments project is making headway on getting formative assessments into teachers' pedagogical and assessment decisions.

The ASSISTments project targets middle school students and teachers in the public school system in Worcester, MA – one of the largest cities in Massachusetts with an estimated 182,596 residents and home to children of many different ethnicities – as well as other schools in the surrounding areas. The content covered in the microworlds is closely aligned with the learning strands presented in the Massachusetts Curricular Frameworks (Massachusetts Department of Education, 2006). By engaging students in scientific inquiry that relates to their coursework as well as reacting to the inquiry skills that they engage in during their experimentation, the microworlds, in the future phases of the project, will make it possible to tutor students on these strategies, helping them improve their inquiry skills. Since interaction with the microworlds can deepen students' scientific content knowledge, it is also expected that this interaction will also positively impact students' science MCAS scores (Gobert, 2009). Furthermore, since the microworlds also hone students' inquiry skills in addition to their content knowledge, the science ASSISTments team presupposes that this will impact their scientific literacy as well (Gobert et al, 2007; Perkins, 1989).

Background

Inquiry in Classrooms

The ASSISTments program utilizes inquiry as its primary means to guide students' learning. Inquiry has long been used in classrooms (Massachusetts Department of Education, 2006); however, until recently hands-on activities were used without providing scaffolding to students. The results in terms of students' knowledge and skills were mixed (Kirschner, Sweller, & Clark, 2004). In the Science ASSISTments project, which utilizes scaffolding and real-time tutoring, students can more deeply engage in learning via inquiry. By doing so, they should be able to more fully understand the scientific concepts presented in the microworlds.

There are some inquiry projects that relate to the Science ASSISTments project. For example, a study jointly conducted by faculty at the University of Wisconsin-Madison and the University of Pittsburgh, tested how well sixth graders think about the goals, strategies, and procedures of experimentation and laboratory activities (Schauble, Glaser, Duschl, Schulze, & John, 1995). Their main purpose in doing this was to learn about the intellectual grasp that 6^{th} grade students have on the goals and strategies of scientific experimentation and also to discover whether or not that understanding could be developed through effective instruction. The study was designed to include a baseline interview that tested students' understanding of experimentation (in the context of a standard, 40-min "hands-on" activity), a 3-week teaching study, and a series of follow-up interviews (Schauble, Glaser, Duschl, Schulze, & John, 1995). Baseline interviews were conducted with a total sample of twenty-one students picked from five participating 6^{th} grade classrooms. The baseline interviews tested students' preexisting ideas about experimentation, then students in all five classes received instruction about the experiment (the effect of weathering on different types of rock), while only one class actually performed it. Two weeks after the instructional unit, another round of interviews was conducted with a sample of thirty-five children from the five classrooms. The study showed that students had difficulty transferring what they had learned during the experiment and applying it to the real world. Thus, they couldn't identify the goals of the experiment, but they understood the logic behind the experiment. The study concluded that experimentation in the classroom is a good pedagogical approach that is often under-utilized or not developed to its full potential, but that without instruction from the teacher, students may not be able to make the connection between the experiment and the real world. In general, experimentation in the classroom was found to engage students in relevant scientific concepts and allow them to learn about experimentation itself (Schauble, Glaser, Duschl, Schulze, & John, 1995).

The idea that experimentation with built-in instruction is better than experimentation in which students are left to their own strategies for learning is supported by a study jointly conducted by faculty at the Max Planck Institute for Human Development in Allemagne and the University of Münster in Allemagne. This study found that students normally focus only on one dimension of different scientific concepts and consider only single properties (Hardy, Jonen, Moller, & Stern, 2006). The study mentioned that students' misconceptions are resistant to change and that in order to broaden their views, students must become dissatisfied with the conceptions they subscribe to and subsequently require a new explanation. Experimentation was cited as a good way to do this (Hardy, Jonen, Moller, & Stern, 2006). The study focused on two types of instructional support within experimentation. The two types of instructional support were high instructional support (HIS) and low instructional support (LIS). In the HIS groups, the teacher sought to elicit students' knowledge using group discussions with statements that related to or contrasted from ideas and hypotheses that students provided. In the LIS groups, the teacher simply served as a supervisor of the group discussions, allowing students to react to each other's hypotheses/ideas (Hardy, Jonen, Moller, & Stern, 2006).

The HIS and LIS received the same curriculum with all of the same materials, except that they had different levels of instructional support (Hardy, Jonen, Moller, & Stern, 2006). A pretest, a posttest, and a follow-up test were administered to the different groups to assess the impact their instruction had on their learning. These tests were made up of multiple choice, free response, and true/false questions that incorporated typical misconceptions. The study found that the LIS group and the HIS group did not significantly differ from each other in their gains from pretest to posttest, but they both had much greater gains than the control group (Hardy, Jonen, Moller, & Stern, 2006). While the HIS group's scores did not change significantly from posttest to follow-up test, the LIS group's scores did decrease a significant amount from the posttest to the follow-up test. The results showed that there was a clear advantage of HIS versus LIS. The HIS group understood the concepts better because they were able to retain the information and knowledge longer as seen in their similar posttest and follow-up test scores (Hardy, Jonen, Moller, & Stern, 2006).

Together, these studies provide evidence that experimentation with proper instruction can serve as a powerful tool in allowing students to visualize scientific concepts in an academic setting and then in transferring those concepts to a real-world setting. Experimentation also provides a useful tool in combating students' misconceptions. A caveat with experimentation is that effective experiments must contain some element of instruction. Instruction that goes hand-in-hand with experimentation leads to both a better understanding of scientific concepts and of the purpose of experimentation itself (Kirschner, Sweller, & Clark, 2004).

Massachusetts Education and Learning Strands

The Massachusetts Science and Technology/Engineering Curriculum Framework is a source from which all public education for science is Massachusetts is based. The framework provides teachers with an outline of different learning strands that must be addressed at certain grade levels as well as a list of expectations of what students at certain grade levels should be able to accomplish.

The framework also states that a good way for students to develop conceptual understanding, content knowledge, and scientific skills is through inquiry-based instruction (*Massachusetts Science and Technology/Engineering*, 2006, pp. 9-11). The framework defines scientific inquiry as "a means to understand the natural and human-made worlds [which] requires the application of content knowledge through the use of scientific skills" and defends its effectiveness by stating that it allows students to draw upon their prior knowledge as well as build new understandings and skills (*Massachusetts Science and Technology/Engineering*, 2006).

The framework is also quick to note that while scientific inquiry is a good basis for instruction, it should not be taught or tested as a separate, independent skill. Rather, the opportunities for experimentation should be part of a well-planned curriculum that include instruction and assessment (*Massachusetts Science and Technology/Engineering*, 2006).

For the middle school grade levels (grades 6-8), the framework expects students to use scientific inquiry techniques and be able to form testable hypotheses, design and conduct experiments, select appropriate tools and technology (i.e. calculators, thermometers, microscopes, etc), make quantitative observations, present and explain data, draw conclusions based on data, communicate procedures and results, offer explanations of procedures as well as be able to evaluate and revise them (*Massachusetts Science and Technology/Engineering*, 2006).

In terms of middle school students' knowledge of the physical sciences (chemistry and physics), the framework expects students to develop their understanding of concepts associated with motion, mass, volume, and energy (*Massachusetts Science and Technology/Engineering*, 2006, pp. 61-68). The physical science learning standards for middle school are grouped under five subtopics: Properties of Matter; Elements, Compounds, and Mixtures; Motion of Objects; Forms of Energy; and Heat Energy. These subtopics each have a number of associated learning strands that serve as a guide in what information and concepts should be covered in middle schools.

This IQP project deals with the second learning strand under the subtopic of "Properties of Matter." This learning strand states, "Differentiate between volume and mass. Define density." This project will use this learning strand as a basis for the creation of a microworld, described later, which engages students in inquiry in the sub-topic of density and challenges common misconceptions regarding density.

Density Misconceptions

A master's student at California State University Northridge and a science teacher as Le Conte Middle School in Hollywood, CA, Esther Dabagyan wrote a paper describing an educator's perspective on middle school misconceptions on density and buoyancy. The information presented in the paper was based on Dabagyan's own classroom experience.

In her paper, Dabagyan describes that density is a "higher order concept," which, according to cognitive theorists like Jean Piaget, is an idea that children under the age of nine cannot yet understand because they do not yet have the developmental capacity to do so (Dabagyan, n.d.). Dabagyan explains that "higher order concepts" such as density can have many misconceptions.

Standard public school curriculum often neglects to recognize that students may have preconceived notions (or misconceptions) on topics such as density (Smith, Maclin, Grosslight, & Davis, 1997). By not acknowledging these misconceptions, schools allow students to hold on to their inaccurate beliefs.

Most often, middle school students' misconceptions of density stem from their inability to relate the basic concepts of density they learned in elementary school to the more advanced mathematical formulas they learn in middle school (Dawkins, Dickerson, McKinney, & Butler, 2008). Also, most middle school students generally tend to break down more complex ideas in order to understand them. In this way, they may understand certain parts of a concept, but they may not understand the concept as a whole. For example, in terms of density, students often focus on the volume element or the mass element, but cannot understand density as a combination of the two elements.

Some common misconceptions with regard to density are: the relationship between mass and volume, the mass and volume relationship in terms of the amount of water displaced, and the material "illusion." Some examples of typical misconceptions in each of these categories are given below.

The Relationship between Mass and Volume

Some students incorrectly assume that large objects will sink and small objects will float, regardless of their density (or apparent weight). This is the misconception that makes it difficult for many people to decide if a large, light object or a small, heavy object can float (Dabagyan, n.d.). This confusion is rooted in a misunderstanding of how mass and volume differ. The understanding of how mass and volume differ is vital in comprehending the idea behind density and floating (Dabagyan, n.d.).

The Mass and Volume Relationship

This misconception deals with the fact that when students are asked to describe why an object displaces water, they often neglect to mention the relationship between mass and volume. Instead, they focus on one of the two variables. While students understand and recognize that there is a relationship between the physical object and displacement, they struggle when explaining this relationship and default to a familiar and similar concept of "weight" (Dabagyan, n.d.).

The Material "Illusion"

Many students assume that there is some intrinsic property of a material that causes it to either sink or float. One manifestation of this misconception is the "air hypothesis" (Dabagyan, n.d.). Students may believe in the idea that objects must have air in them or must have a certain area exposed to air in order to float (Dabagyan, n.d.). The air hypothesis is one of the hardest to dispel (Duckworth, 2001).

Experiments in Addressing Density Misconceptions

Many researchers and instructors have conducted studies on the different ways student experimentation with density affects these misconceptions. In particular, Carol Smith, a cognitive developmental psychologist and a faculty member at the University of Massachusetts – Boston, has conducted a number of studies on this subject.

One study Smith and her associates conducted investigated whether or not students in the 6th grade could distinguish between weight and density and consequently apply the concept of density to a situation of sinking/floating. The two goals for the study were to help students create a concept of density that did not include weight and volume and to help build students' awareness of modeling as a scientific tool (Smith et al., 1986).

The teaching study was done with a 6th grade class at the West-Marshall School in Watertown, MA (Smith et al., 1986). There were nineteen students (seven girls and twelve boys) ranging in age from eleven to twelve years. The study was done in three stages: individual pretest interviews, presentation of instructional material to the whole group (given in a series of eight lessons), and individual posttest interviews. The interviews were divided into three parts: ordering objects with reference to their weight, size, and density; exploring ideas about what makes objects weigh; and articulating ideas/explanations/hypotheses about what makes objects sink/float. Teaching sessions lasted 1 – 1 ½ hours, twice a week and were held in computer labs.

The results showed that by the posttest interview, 2/3 of the students were able to discuss density and weight separately. They were also able to effectively use computer models to relate ideas about density. Also, half of the students were able to correctly use their knowledge of density to order objects. Overall, students were able to better understand the concept of density as a result of the teaching and modeling. The majority of children – but not all – were able to correctly use the model in order to support their understanding of density. The reason that some children still did not have a proper grasp of the subject material might have been because not enough time was spent reviewing the concepts (Smith et al., 1986).

A more recent two-part study by Smith was designed to investigate the effectiveness of having students develop their own conceptual models and then introducing them to conceptual models that researchers had developed (Smith, Snir, & Grosslight, 1992). The idea was to have students explore the phenomena and hopefully find problems with their current conceptual model of weight and to correct their models to include density. The studies used a pretest and a posttest to determine the effectiveness of the course that taught 6^{th} and 7^{th} graders the concept of density. During the pretest and posttest students were given a task to perform and were asked to explain the rationale behind their choices; researchers then took their answers and placed students into different categories. In study one, the categories included undifferentiated weight-density, transitional, and differentiated weight-density. For study two, the categories were undifferentiated weight-density levels 1 and 2, and differentiated weight-density levels 1 and 2. The movement of students from one category to another, before and after the course was used as an indicator of the course's effectiveness.

The results of study one showed that there was an improvement in students' skills at differentiating between weight and density, but the researchers claimed there was still considerable room for students to improve. The results didn't show much improvement in students' ability to understand sinking and floating. However, the models created by students to explain their rationale for their choices during the ordering task showed an improvement in the attributes of the objects the students choose to represent. Specifically, they went from mostly size and weight characterizations during the pretest to the posttest where a few characterizations included density. Nevertheless, there was still evidence that many students still had a lack of understanding of the relationship between mass, volume, and density (Smith, Snir, & Grosslight, 1992).

The results from study two showed slightly better results when compared to study one in the area of weight-density differentiation. The flotation task in study two had a much better result than in study one. Where in study one not very many students made any improvements to their understanding of relative density and its relation to floating, in study two almost all students made some sort of conceptual change in their model. This shows that students had a better grasp of the relationship between weight, volume, and density versus how the relative density of an object determines if it floats (Smith, et al., 1992).

The ASSISTments Density Experiment

This Interactive Qualifying Project worked on the design of three ASSISTments microworlds for density. Using the previous findings gathered from the studies described above, from the WPI ASSISTments team, and from the Massachusetts Curriculum Framework, a computer microworld was programmed by the Science ASSISTments software engineers that would engage and assess middle school students on the concepts of density with the goal of addressing their misconceptions as well as honing their inquiry skills.

After several revisions to the wording and design of the original microworld (Appendix 1), a final microworld was created for pilot testing. The final design also eliminated some of the sections initially included in the original microworld in order to create a microworld that could be completed in the given time constraints. This design consisted of an inquiry pretest, a knowledge pretest, three microworld experiments each addressing a certain topic or misconception in density, and a final posttest. The Method section describes and outlines the purpose of each pretest, microworld, and posttest given to the students for the pilot test. A complete collection of the tests created can be viewed in Appendices 2-10.

Method

Participants

Participants included a group of eight eighth grade students and one ninth grade student drawn from an after school program in an urban district of the Northeastern U.S.

Procedure

Each student was tested individually on a computer in a computer lab in a private university in the North Eastern United States. First, they performed the Inquiry Pretest to gauge their skills: to make and test a hypothesis, identify independent and dependent variables, and interpret data. Secondly, they did a Content Knowledge Pretest to assess their general understanding of density. Independent and dependent variables were explained briefly before each question.

Next, they were asked to complete the Volume Exploration, Density Balance, and Archimedes Microworlds. Each microworld asked them to form a hypothesis and identify variables to test in the experiment. Each student was then given the opportunity to experiment in the microworld, manipulating any of the given variables and recording results as they went. After they had finished the experiments, the students completed the assessment activities by reexamining the given question and their original hypothesis.

Finally, the students were given a posttest to test their overall knowledge and understanding of density. This was a multiple-choice test that compared the densities of various objects and liquids.

Materials

The following section describes the pretests and microworlds. These can be seen in Appendices 2-10; the ASSISTment system can be found at www.ASSISTments.org.

Pretests

Inquiry Pretest

The purpose of the Inquiry Pretest was to collect data on the students' skills regarding their knowledge of hypothesis-formation, independent and dependent variables, the control for variables strategy, and data interpretation. For this we used a subset of inquiry items developed by the Science Assistments team. This data was used to evaluate each student's performance both during and after the Microworld, and to characterize how students used their inquiry skills within the microworld. A copy of the inquiry pre and post-test can be found in Appendices 2-6.

Inquiry Pretest 1 (63802, Appendix 2):

In the first Inquiry Pretest, the students were told, "A student has a wagon of a certain mass. He plans to investigate how the acceleration of the wagon changes as the force he exerts on it increases". They were then asked to identify the independent and dependent variables. This showed if students were able to understand the concept of independent and dependent variables.

Inquiry Pretest 2 (63803, Appendix 3):

In this section, the students were given an example of a hypothesis: "If the amount of sugar increases then the candy bar will taste sweeter" and were asked to identify the independent and dependent variables in the hypothesis. Once again, this showed whether or not students were able to identify the independent and dependent variables within a problem scenario.

Inquiry Pretests 3 (63989) and 4 (29462) (Appendices 4 and 5):

The students were given the following situation in the third inquiry pretest: “Homer notices that his shower is covered in a strange green slime. His friend Barney tells him that coconut juice will get rid of the green slime. Homer decides to check this out by spraying half of the shower with coconut juice. He sprays the other half of the shower with water. After 3 days of the ‘treatment’ there is no change in the appearance of the green slime on either side of the shower”.

The students were given five options from which to choose an independent and dependent variable. They were also given five more options from which to choose a valid hypothesis for Homer’s experiment. This inquiry pretest went more in depth than the previous pretests. It asked the students to examine an experiment and identify more than the independent and dependent variables; it also demonstrated their understanding of hypotheses.

Inquiry Pretest 5 (29464, Appendix 6):

In the last inquiry pretest, the students were given an experiment and its results in a data table. The experiment was described as, “A class investigating the motion of a tire swing collected the data in the table below. The students were able to draw conclusions about the factors that affect the motion of a swing. Two students from the class decide to use the class data to build a different-size tire swing in their backyard. They build the tire swing shown in the figure”.

The students were asked, “After testing the swing, they decide that they want to make it swing faster. Based on the data from the class investigation, what could the students do to make their tire swing move back and forth faster?” and were then prompted to explain their answer. This inquiry pretest was also more in depth than the previous test, and asked students to be more descriptive in their reasoning. The purpose of this test was to examine the students’ skills at interpreting data and reach scientific conclusions in a more difficult experiment.

Content Knowledge Pre- and Post-test

The content knowledge pre- and post-test was designed to gather data specifically on students’ knowledge of mass, volume, and density, as well as to identify any misconceptions they had regarding these topics (as evidenced in the pre-test), and whether our materials helped with these (as evidenced in the post-test).

Knowledge Pretest 1 (62956, Appendix 7):

The students were given a picture of three different sized boxes of cereal. They were first asked to choose the box that could hold the most cereal, and then which box had the largest volume. Since the answers to the two questions should be the same, this pretest allowed us to see if students understood both the concept and definition of volume.

Knowledge Pretest 2 (62958, Appendix 8):

In the second pretest, students were presented with a picture of two different sized stacks of cereal boxes and were told that stack A had 8 boxes of cereal and stack B had 16 boxes of the same cereal. The students were then asked which stack had the largest volume, which stack had the largest mass, and which stack had the highest density. This pretest was used to determine if the students could relate mass and volume to successfully determine density.

Knowledge Pretest 3 (62961, Appendix 9):

In the final knowledge pretest, the students were again given three boxes. The boxes had the same size, and the students were told that they also had the same volume. The students were asked which cereal box had the highest density and had to choose their answer from the following options: box A, box B, box C, and not enough Information. This part was used to determine if the students understood that density was not only dependent on volume.

The last question was an open response that asked students what additional information was needed in order for them to be able to determine density. If the students chose mass, for example, then they demonstrated a strong understanding of density and the relationship between mass and volume.

Density Microworlds & Tasks

Microworld One: Volume Exploration (Appendix 10)

Objective

The objective of this Volume Exploration Microworld is to give students a chance to demonstrate what they understand about the concept of volume, as well as to experiment in order to solidify their basic understanding. It is critical that students understand the concept of volume before moving on to apply it to their understanding of density. The questions posed in the knowledge pretest are aimed to identify if students understand density at a conceptual level, and then if they can relate that to the term itself. For students that showed strong knowledge of this topic in the pretest, this microworld will serve to further reify their understanding. For those students with a partial understanding of this topic, this microworld will build their understanding through guided experimentation.

Experiment One: Size and Volume

The first part of the microworld provides an opportunity for students to conduct experimental trials to better understand the relationship between the size of a container and its volume. Students are presented with three containers labeled a, b, and c. They are told the containers have all the same dimensions except for height; the three containers are obviously different in height. Students are asked, “Which container do you think would hold the most water?” to determine if they understand volume. Specifically, even if they cannot provide a definition or a formula for volume, students may have a conceptual understanding that can be assessed using a visual representation such as this one (Appendix 10A). Students can choose their answer by clicking on a radio button, which only permits them to choose one answer. They are then asked to write a hypothesis to describe the relationship between size of the container and its volume. They are told here that “by volume we mean how much of a substance it can hold,” in case they are not aware of the terminology. This will give researchers an opportunity to assess students’ explanation for their answer to the preceding question, as well as to see how well students are able to construct a hypothesis.

Once they enter a hypothesis, students are shown three measuring cups with the prompt, “Now, test your hypothesis. Below, the water from each has been emptied into measuring cups.” This allows students to relate the size of the previous containers to a measurement and allows them to see the relationship between container size and volume. Students are then asked two follow-up questions: “Which container has the most water in it?” and “Which container has the largest volume of water?” Both of these questions have students choose a, b, or c on a radio button. The first question is aimed to see if students are able to recognize the volume differences based on the measuring cups, and the following is to see if they are then able to relate it to the term volume.

While this microworld is significantly less interactive than the following ones, it involves essential background material for further exploration in density. A screen shot of this microworld can be found in Appendix 10A-B.

Microworld Two: Density Balance Microworld (Appendices 11-12)

Objective

The objective of this Density Balance Microworld is to give students an opportunity to experiment with mass and volume together for the first time. They are given a set of scales, and asked to conduct experiments to determine if the size (or shape) of a container impacts mass and then if the type of liquid will impact mass. This is one further step to conducting experiments with density as the type of liquid is introduced as a variable in this exploration. This microworld also serves to remediate misconceptions on shape and mass, essential before further investigations. Students are introduced to this set of microworld assessment activities with the following prompt: “This portion deals with the differences in liquids and the effects of the containers that hold them. It has two sections.”

Experiment One: Size of a Container and Mass of Liquid (Appendix 11)

The students are first told they will be “determining if the container size has an effect on the mass of the liquid.” They are initially asked: “Do you think the shape of a container affects the mass of the liquid it contains?” They are able to choose only yes or no via a radio button. This is aimed to see if students have a prior understanding of the relationship between container size and mass. A yes or no response instead of a text box response makes auto-scoring analyzing possible (discussed later), and allows more focus on the data analysis section of the scenario. Next, students are given the following excerpt to introduce them to the experiment set up:

> Below are two containers on a scale and a table for collecting data. Add or subtract liquid from each container until you think the two sides are balanced. Then click the "Record" button, this will record data from the scale onto the table. Use your data to answer the following questions.

Students are given the option to change the substance (water/oil) and shape of the container (narrow/wide). This is to see if they are able to use the control for variables strategy on their own, given the goal of the experiment. Their data is logged only when the scales are balanced, to prevent them from recording and analyzing data with mass as a variable. In this sense, the design has a built-in control for mass as a variable and allows students to simply focus on the variables at hand – liquid type, container size, and volume.

All of the students' data from their experimental trials are added to a table below the microworld. It has columns for "Used CVS," "Trial Number," and then two sections to describe the variable values for each side of the scale; shape, liquid type, volume, and mass are recorded per side for side-by-side analysis. Students are asked: "What can you conclude about the relationship between the shape of the container and the mass of the liquid" This helps them look back at their data to see if they can draw any conclusions about the experiment they conducted. Their answers will help determine if they were able to draw a correct conclusion. They are finally asked to check off which trials they are basing their conclusion on to see if they were able to connect their conclusion to specific data in their experiment. Their answers to this will help determine if the trials they ran were in support of the goal of the experiment; in the science education literature, this is referred to warranting one's claim with data. A screen shot of this microworld can be found on Appendix 11.

Experiment Two: Size of a Container and Type of Liquid (Appendix 12A-B)

Students are given the same microworld to explore the relationship between type of liquid and mass. Once again, they are asked if they think the type of liquid will affect its mass; this is a yes or no radio button question that will help determine if the student has prior knowledge about the topic. Students are asked to write a hypothesis to describe the relationship between the type of liquid and its mass, which provides an explanation rationale to their answer for the previous question. Students are then given the same set of instructions to interact with the microworld as they were given in Experiment One.

After experimentation, they are asked, “When both containers are of equal mass, which liquid has the largest volume?” This question determines if students can draw the correct conclusion from their set of data; this targets the data interpretation strand of the National Science Education Standards inquiry skills (NSES, 1996). They are given “water”, “oil”, and “they are the same” as radio buttons for their choice of answers. Once again, they are asked which trials they are basing their conclusion on to see if they are able to warrant their claim with data. They are then asked, “What can you say about the relationship between the type of liquid and its mass (given the same volume)?” This response will help assess if the student has gained knowledge based on their experiments and data analysis. A screen shot of this microworld can be found on Appendix 12.

Microworld Three: Archimedes Microworld (Appendices 13-15)

Objective

The objective of this Archimedes Microworld (62951 and 62952) is to introduce the concept of displacement with respect to an object's mass, volume, and liquid type. Each of the three scenarios within this microworld is aimed to remediate specific misconceptions around these ideas, as well as to give students an opportunity to develop their understanding via exploration with the microworld.

It is important for students to see the relationship between the volume of water (or any other liquid) displaced and the volume of the object submerged. This is especially apparent in misconceptions surrounding orientation. That is, it is highly likely that students may think that submerging an object vertically rather than horizontally will displace more water. The second scenario involves analyzing the impact of the liquid on displacement. This is important because it serves to remediate the misconception that displacement is solely impacted by attributes of the object. The final scenario asks students to extend their understanding from previous experimentation to consider what makes an object sink or float. It is intentionally a more open-ended experiment. This will enable students to gather what they have learned from their previous experiments in order to use the control for variables strategy to design and conduct their own experimental trials. It is also a major opportunity for analyzing student skills to use cvs, as well as to assess their explanation as part of a more open-ended experiment. They will see that objects will float if they are less dense than the liquid, and vice versa. These microworlds can be found in Appendices 13, 14, 15.

The Experiments (Appendix 1 3, 14, 15)

The students are given the following explanation to introduce them to the concept of displacement:

> Displacement can be described as the amount of liquid that is replaced by an object when it is dropped into the liquid. For example when you drop an ice cube into a glass of water, the water level increases by the volume of ice that is submerged in the water. Displacement can be measured by the amount of liquid that overflows from the larger container into the smaller container.

Here, the definition of displacement is given so that students that are unaware of the topic are still able to fully participate in the activity. An example is given to help students connect the definition to familiar situation. This allows students to visualize the concept of density even if they find the formal definition of displacement difficult to understand. Finally, it is connected to the microworld so that students are aware of how it specifically relates to their experimentation.

Students are then further introduced to the microworld design by being told: “Next you will see two containers. When the object is dropped into the larger container, liquid will be pushed (displaced) from the larger container into the smaller container.” This explains specifically what the microworld will look like, so students can think about what they will be doing when answering the preliminary questions.

After these initial instructions, students are asked the specific guiding question for the first scenario: “Does flipping or rotating an object (this is the object’s orientation) affect the amount of liquid it displaces? Write your hypothesis below.” This introduces the students to the concept of orientation as the familiar action of flipping or rotating an object. It asks students to think about the impact of changing the object's orientation on displacement; their answer can be observed for level of correctness, as well as their skill at reasoning about a hypothesis with independent and dependent variables. Students are then asked to use check boxes to choose the variables they will use to test their hypothesis; this will theoretically help the students to use the control for variables strategy as they will be forced to thoughtfully consider how they are going to test their hypothesis. Their choices here can be compared to both the variables suggested in their hypothesis as well as the experiments they conducted to look for consistency and use of the control for variables strategy.

In each of the three scenarios students are asked to then test their hypothesis using the microworld. They are told: "Use the drop down menus to change the values of relevant variables, and then press the 'Drop Object' Button to gather data in the table below. Press 'Reset' to repeat as necessary until you are done collecting data." These instructions serve a two part function: first they are used to generally guide students' interaction with the microworld; it also provides scaffolding to the student both to change only the "relevant" variables and repeat data collection until they have enough data.

The screenshot of this microworld can be viewed on Appendices 13, 14, and 15. Notice that there are measurement amounts on each container; these are to make students aware of the amount contained in each. The "Drop Object" and "Reset" buttons are placed below the containers to make them easily accessible in terms of usability and understandability. Students have the option to use drop down menus for liquid (water/oil), mass (50g/100g), volume (100 ml/200 ml), and orientation (vertical/horizontal). Two options per variable were chosen to provide students with the option to look at different scenarios without overwhelming them with too many possible combinations.

All student data is recorded in a table for students' data analysis. The columns from left to right are "Used CVS," "Trial Number," all attributes of the object (mass, volume, density, orientation), all attributes of the liquid (type, density), then the mass displaced and the volume displaced. Separators divide the first two columns, the object columns, the liquid columns, and the displacement columns to help students understand and interpret data. It should be noted that object and liquid density is not an option to change, rather it is a calculated variable; it is crucial to offer this data because it begins to introduce the concept of density with respect to the experiment. The mass and volume displaced columns are placed side by side to further enforce the idea to the students that the mass and volume displaced are related.

Once students fill their table with data and are ready to continue, they are prompted to look back at their data to choose by checking off the designated column the trials in which they used the control for variables strategy. They are told that the strategy "is when you only change the target (the variable you are changing) and keep the other variables constant." This permits students to look back and see if they are using the strategy, and their choices will provide an assessment of whether they understand what the target variable is. Students are then asked to look at the trials they used the control for variables strategy, and check off the trials where they only changed the variable for orientation. They are then prompted with: "Now looking at these specific trials, what does the data tell you about the orientation of an object and the amount of liquid it displaces?" This ensures that students are able to conduct a proper analysis of the relationship between displacement and orientation; that is, it forces students to use the control for variables strategy so they are drawing conclusions only using relevant data. This may not work, however, if students did not record trials that use the strategy, or if they misunderstood the check box instructions.

The second scenario follows similar format, asking students: “Do you think the type of liquid affects displacement?” Here, their data from their trials are additionally added to a “Liquid displaced versus Object Mass” graph. This will give them one more tool to analyze their results. They are again asked to choose trials with the control for variables strategy. Students are then asked, “How is displacement affected by different types of liquids?” and then told to choose the trials that they are using to warrant their claims.

Finally, in the third scenario, students are first asked to select which variables they think will affect whether or not an object will sink or float. Their answers can be based on their prior knowledge or experimentation during the previous assessment activities. Students are asked to explain what they are basing this prediction on. This will encourage students to think about how and why each variable will impact whether or not an object sinks or floats; it will also provide an opportunity for researchers to analyze their reasoning. After experimenting, they are, once again, told to select the trials in which they used the control for variables strategy. Next, they have to check off which variables affected whether or not an object sank or floated in their experimentation; this will enable students to change their prediction or reaffirm their initial prediction given their data. Finally, they are asked to write a summary of which variables they chose. This step encourages students to look back at their data one last time and explain which variables impacted whether or not an object sank or float.

Post Tests & Transfer Assessment (Appendix 16)

After students complete the microworld assessments, the students' understanding of inquiry and of density are assessed again, using the same items as in the two pre-tests, respectively. This will help identify any specific changes in student inquiry and /or content knowledge after participating in the experimentation with microworlds. Additionally a transfer task was designed to assess whether students could transfer what they had learned to new types of items. Here, students were given nine different combinations of objects and liquids, and were asked to determine if the object will sink or float in each. Students were given the densities of each. The liquids (salt water, rubbing alcohol, and liquid mercury) and objects (lead ball, wood ball, and rubber ball) were intentionally chosen to be familiar materials with very different densities. All the assessment and transfer items were presented to the students online through the ASSISTments system. Unfortunately, since the portions of the pretest and posttest used the same problem sets some data was lost due to the ASSISTments systems logging mechanism. When the students were retaking these problem sets during the posttest, the ASSISTments system recognized this and did not log the results of these post-test. The ramifications of this will be discussed in the Suggestions for Further Data Collection section. No other materials were needed. These items can be seen on Appendix 16.

Microworld Data Extraction

Problem Statement

A portion of our data, those from students' interactions within the microworlds, required us to extract and analyze data stored by the Assistments platform and the microworlds contained within Assistments. An analysis program will be needed to extract data, perform portions of the analysis on this data, and output this data in a clear format.

Domain

Introduction

The parsing and analysis program will provide us with a consistent and easy way to grade, analyze, and view the data gathered during the experiment.

General Knowledge

As a result of the microworlds' data being stored as XML, the analysis program was designed using a lexer and parser to extract the data from the database output. The parser then inserts the extracted data into data structures to then be manipulated on a student by student basis. A more technical description can be found in Appendix 17.

Customers and Users

The program was designed to be used by administrators of the study. It thus needed to output the data in an easy to understand format, such as HTML or Excel.

Environment

This program was used on systems that contain a python interpreter with the ply module installed.

Scope

The analysis program has several components. The first component is the parser which extracts data from the database log and constructs students based off of the problems they answered in Assistments. The second component reconstructs the trials performed by the student within each microworld, analyzes the data, and determines if the student used certain experimentation strategies such as control for variables and if they manipulated the independent variables they specified in order to test their hypothesis. The final component outputs the data into either an Excel or HTML file.

Requirements

Program Features

1.1 Contains a lexer and parser that will correctly extract problem data and microworld actions from the database output.

1.2 Reconstruct the trials conducted by each participant in the experiments and identify the independent variables for each of the students' hypothesis.

1.2.1 There can be any number of trials conducted and independent variables tested.

1.2.2 There is only one hypothesis per Assistment.

1.3 To analyze the data we needed to output each student's trials by Assistment and whether the student used the CVS, what variables the student manipulated for each trial, and what variables the students choose to manipulate to test their hypothesis.

Platform

1.4 Python with ply module.

Data Model

Introduction

The program constructed five different data models. The first was a representation of a student who was part of the experiment. The second was a representation of an Assistment. The third was an action performed within the microworld. The fourth data model represents a problem answered by the student within the Assistment. The fifth model represents the answers to a problem.

Student Data Structure

The student data structure contained the following data, the student's name, and a collection of the Assistments that the student completed. The student structure was also required to add problems dynamically to Assistments based off of the Assistments' id number. If the Assistment does not yet exist for the student, the system created a new assistment with that id number.

Assistment Data Structure

The assistment data structure contains the assistments id number and a collection of problems that were answered. The assistment structure also needed to be able to add problems dynamically to itself, prepare itself for analysis, and rebuild the data table from the students actions within the microworld.

Action Data Structure

The action data structure contains the text representation of the action, its number, and the source of the action. The action structure also needs to clean itself for analysis, determine if it was performed during the initialization of the microworld, find all the variables within the action text, and extract the data from these variables.

Answer Data Structure

The answers data structure contains some of the following: whether the student answered correctly (true or false), the answer's number, the student's open response, and a collection of answer values (if the answer required more than one selection). It needed to be able to prepare these values for analysis, such as removing extraneous text, such as carriage returns and quotation marks, from the collection of answer values.

Problem Data Structure

The problem data structure contains all the data for each problem from the database output. This includes the answers to the problem, the assistment it was a part of, the actions performed within the microworld while the student was answering the problem, and the identification of the student who answered the problem. The problem structure needed to be able to prepare itself for analysis, extract the answers from the database output, and extract the actions performed within the microworld.

Coding of Students' Data

The students' data were analyzed with respect to both their prior knowledge in terms of inquiry skills and content knowledge. Many of the questions in the pretests, questions within the microworld activities, and posttests were autoscored by the program. In these cases, students received one point for a correct answer, and zero points for an incorrect answer. The open response questions, namely list items here were hand coded with respect to several elements. Open response questions were included in both the pretests and microworlds, and ranged from explanations to hypotheses. A coding scheme was created for each type of open response question to thoroughly and consistently grade the student's responses. In order to analyze the students' progress through the microworlds, the coding was based on identification of key elements of the questions, making connections between the elements and completeness. Some aspects were graded 0 or 1, indicating that the student either correctly answered (awarded 1) or did not (0). The quality and completeness of the open responses were coded for 0-2, which allowed for partial correctness. For open response hypothesizing and explanation questions, student responses were coded with respect to correctly identifying the independent variable (0 or 1), the dependent variable (0 or 1), the relationship between the two (0 to 2), and for quality/thoroughness of explanation (0 to 2). For questions asking students to create a hypothesis, they were also graded on how closely it followed the structure of typical scientifically sound hypothesis (0 to 2). Finally, questions that asked to make a conclusion on the experiment were graded based on the relationship between the variables (0 to 2) and the quality of the response (0-2).

Results

The following two tables summarize student performance on the pilot test for each of the pretests, inquiry and density, respectively. The first table shows student scores as a percent for each inquiry sub-category: independent variables, dependent variables, hypothesis, data interpretation and the control for variables strategy.

Table 1: Inquiry Pretest Sub Category Scores

Inquiry Pretest Sub Category Scores

Student	**IV**	**DV**	**Hypothesis**	**Data Interpretation**	**CVS**
One	25%	50%	0%	0%	75%
Two	50%	50%	0%	100%	25%
Three	50%	50%	50%	100%	75%
Four	50%	25%	0%	0%	25%
Five	50%	50%	100%	0%	75%
Six	25%	50%	50%	0%	75%
Seven	50%	50%	100%	100%	75%
Eight	50%	50%	50%	100%	50%
Nine	75%	50%	50%	0%	50%

Similarly, the following table shows student performance on the content knowledge pre-test for each content area:

Table 2: Knowledge Pretest Sub Category Scores

Knowledge Pretest Sub Category Scores			
Student	Volume	Mass	Density
1	67%	100%	100%
2	100%	100%	67%
3	33%	100%	0%
4	100%	0%	67%
5	67%	0%	67%
6	67%	100%	67%
7	100%	100%	67%
8	100%	100%	67%
9	100%	100%	67%

This data can be further summarized into overall inquiry and knowledge scores. In order to examine the microworld interaction based on students' prior knowledge in terms of inquiry and content knowledge, students were placed into groups for later analysis. A summary of student scores on the pretests as well as their grouping can be seen in the table below:

Table 3: Student Grouping and Pretest Scores

Student Grouping and Pre-test Scores				
Pretest Grouping	**Student**	**Inquiry Score without open response**	**Inquiry Score with open response**	**Content Knowledge Score**
Low inquiry, High content	1	45.5%	20.0%	85.7%
	2	27.3%	60.0%	85.7%
	4	27.3%	33.3%	71.4%
High inquiry, High content	7	63.6%	66.7%	85.7%
	8	45.5%	66.7%	85.7%
	9	54.5%	60.0%	85.7%
Moderate inquiry, Low content	3	54.5%	53.3%	28.6%
Moderate inquiry, Moderate content	5	63.6%	53.3%	57.1%
Moderate inquiry, High content	6	36.4%	40.0%	71.4%

Notice here that the inquiry scores are given with and without the coded grading for the open response questions. This is to enable comparison across automated responses as well as within graded responses, because one student did not complete that section which placed him in a low inquiry group. Groupings were made based on the complete inquiry score, but it is necessary to note that groupings would have been different if relying on solely automatically graded answers and not including the open response data.

The following section describes analysis of each student’s performance on the pilot test for the pretests, microworlds, and posttest. Following the case descriptions, there is a section to compare students within similar pretest groups to compare their explorations in the microworld activities to find commonalities.

Student One

Background Information

Student one is a male thirteen year old in eighth grade. In the background survey it was revealed that his favorite classes in school are gym and math, however he usually finds science easy and enjoys it at all times. He states that his grades are consistently in the “A” range. He additionally provides that his parents have Masters or Graduate degrees.

Inquiry Pretest Results

Student one scored an overall 20% on the inquiry pretest. On the first pretest question (63802), he was unable to identify the independent variable; instead, he responded with the dependent variable. He correctly chose this same variable when asked to identify the dependent variable. On the second question (63803), he was again unable to identify the independent variable, again choosing the dependent. For this question, he incorrectly completed the hypothesis, choosing the independent variable, unlike in previous questions in which he consistently chose the dependent variable. On the third question (63989), the student was able to identify the independent and the dependent variable; he was unable, however, to identify the dependent after the experiment took place. On question four, when asked how he would go about conducting an experiment (29462), he chose the incorrect option to “keep some variable constant, and change other variables, especially the variable you are testing”. On the fifth question (29464), the student was not able to correctly determine how to make the swing go faster, and was therefore unable to explain his answer; he lost four points here for this (relating to the low overall score). For the sixth question (29465), he was able to correctly identify how to control an experiment for a vaccination test. He was also able to identify a control for variable strategy in questions seven (45720) and eight (45721) in a plant light experiment.

Overall, it can be inferred from the items that student one had a relatively good understanding of what a dependent variable is. However, he was consistently unable to identify the independent variable. He was not able to complete or write a hypothesis. Since student 1 chose the option to “test multiple variables in experimental design”, this would suggest that he does not have a solid understanding of the control for variables strategy; this is inconsistent with his consistently correct responses to the control for variables questions. It should be noted that student 1 scored a 20% because while many of his multiple choice answers were correct, his score was greatly lowered because of the open response grading system.

Content Knowledge Pretest Results

Student one scored an overall 85.71% on the knowledge pretest. Student one was able to correctly answer the first question on volume demonstrating that he understands both the terminology and concept of volume. However, for the second question (62958), he was unable to determine that the stacks had different volumes, which shows he may not fully understand the concept of volume. He was able to identify the stack with the larger mass. He also recognized that they would have the same density. On question three (62961), the student recognized that there was not enough information to determine which box had the higher density; he explained that you would need to know if the contents of the boxes were the same to determine which has the highest density.

Microworld 1: Volume Exploration Results

Student one was able to correctly identify the container that held the most volume in question 63990. His hypothesis was good, i.e., it correctly identified the independent variable, dependent variable, and the relationship between the two. After experimenting with the microworld, he was able to confirm his initial answer to identify the container that held the most volume. He was able to answer this correctly for both the concept question and the terminology question. This demonstrates that he understands the concept of volume.

Microworld 2: Density Balance Results

Student one started the density balance Microworld with the first scenario on shape by incorrectly believing that the shape of a container affects the mass of the liquid if holds. The trial data shows that this student conducted two identical trials that successfully isolated shape. After experimenting, he was able to make a strong conclusion to identify the correct relationship between shape of the container and mass of the liquid. For the second scenario, the student answered correctly that liquid type will affect its mass. He performed two trials changing only liquid type. These results demonstrate that student one was able to use a control for variables strategy in his experimentation. After experimenting, he was able to form a good hypothesis, which identified the dependent and independent variables; he additionally mentioned the impact of liquid mass on this result. He was unable to offer any conclusions for the relationship between the variables, so only received partial relationship and quality points. For the third assessment task, the student was able to correctly identify which liquid would have greater mass. His conclusion after the experiment confirmed his choice. However, since he did not provide an adequate explanation, he once again only received partial credit.

Microworld 3: Archimedes Results

For the first scenario in the final microworld, student one correctly identified that an object's orientation does not affect displacement; while his response was not exactly a hypothesis, the quality of his response demonstrated that he understood why rotating an object would not have an impact on displacement. Student one performed six trials in his experimentation. The trials consisted of only two set-ups, which were identical except for object orientation. He correctly identified that all of the trials used a control for variables strategy. His conclusion after experimentation echoed his initial belief.

For the second scenario on type of liquid, he incorrectly wrote that type of liquid does not affect displacement. His response was not in hypothesis form, and lacked an in depth explanation. Student one conducted four trials. The trials use a control for variables strategy in pairs of changing both object orientation and liquid type. While student one changed more than the target variable, he conducted sufficient pairs of set ups to control for liquid type. After experimentation, he was able to conclude that type of liquid does impact displacement; his response was of considerable high quality, he even related the concept of liquid density to the relationship. For the final scenario in this microworld, he explained that he was basing his prediction on both prior knowledge and experimental data analysis. This student conducted four trials changing mass and liquid type. Because he did not test orientation, it demonstrates that he perhaps gained understanding from the orientation microworld experimentation. He did not, however, test for object volume, which does play a role in whether an object will sink or float. His summary after experimentation led him to identify two of the three possible variables that impact whether or not an object will sink (mass, type of liquid).

Overall, the data from his experimental trials in the microworld shows that student one that had a strong grasp of how to conduct an experiment in order to test a hypothesis. This was seen in his consistent use of the control for variables strategy, and the absence of excessive and unnecessary trials. After experimenting in the Archimedes microworld, he was able to target three of the variables that cause an object to sink or float, and keep constant the variable (orientation) that does not make an impact. This shows that he perhaps gained understanding from the prior microworlds.

Post: Combination Sink/Float Results

Student one was able to correctly identify all combinations.

Student Two

Background Information

Student two is a male thirteen year old in the eighth grade. In the background survey it was revealed that his favorite classes in school are history, science, and English. He explains that he finds science somewhat easy, but enjoys learning it at all times. He states that he most of his grades are in the “B” range and he receives mostly “C” range grades in science. He additionally provides that his parents have Masters or Graduate degrees.

Inquiry Pretest Results

Student two scored an overall 60% on the inquiry pretest. On the first pretest question (63802), he was able to identify the independent variable. He was unable to determine the dependent variable, choosing the mass of the wagon as his answer. On the second question (63803), he was unable to identify the independent variable, choosing the dependent variable instead. For this question he incorrectly completed the hypothesis. On the third question (63989), the student was again unable to identify either the dependent or independent variable; he was able, however to identify the dependent variable after the experiment took place. On question four, when asked how he would go about conducting an experiment (29462), he chose the incorrect option to keep some variable constant, and change other variables, especially the variable being tested. On the fifth question (29464), he was able to correctly determine how to make the swing go faster. His explanation awarded him full credit for the problem (7 points) because he was able to identify the independent and dependent variables and the relationship between the two. For the sixth question, the student was able to correctly answer the question regarding the control for variables strategy. However, he was unable to correctly answer the control for variables strategy questions in the seventh and eighth questions.

Overall, student two was not able to consistently identify independent and dependent variables. All of his responses to the questions involving a control for variables strategy were incorrect except for one. This demonstrates that student two is unable to fully recognize the control for variables strategy. Despite these incorrect answers, he was able to strongly support his reasoning behind his answer in the swinging pendulum situation. This may imply that student two is confused by the terminology presented (independent and dependent), but may be able to logically analyze a problem. It should be noted that student two scored a 60% despite many incorrect answers because of the open response grading system.

Knowledge Pretest Results

Student two scored an overall 85.71% on the knowledge pretest. Student two was able to correctly answer the first question on volume demonstrating that he understands the terminology and concept of volume. For the second question (62958), he was again able to determine that the stacks had different volumes, which show that he most likely understand volume. He was able to identify the stack with the larger mass. He was unable to recognize, however, that they would have the same density. Because the student answered that the larger stack would have higher density, he most likely does not fully understand the concept of density fully. On question three (62961), the student recognized that there was not enough information to determine which box had the higher density. He explained that you would need to know the amount in container, which makes it seem like he is relating density to mass. This also shows that he may not fully understand density.

Microworld 1: Volume Exploration Results

Student two was able to correctly identify the container that held the most volume in question 63990. His hypothesis identified the independent and dependent variables, but he was not able to draw a specific relationship between them. After experimenting with the Microworld, he was able to confirm his initial answer on which container held the most volume. He was able to answer this correctly for both the concept question and the terminology question. This demonstrates that the student understands the concept of volume.

Microworld 2: Density Balance Results

Student two started the density balance Microworld with the first scenario on shape by incorrectly believing that the shape of a container affects the mass of the liquid it holds. Student two conducted three experiments. He was able to change only the shape of the container using a control for variables strategy. After experimenting, he was able to make a good conclusion to identify the correct relationship between the shape of the container and the mass of the liquid. For the second scenario, he answered correctly that liquid type will affect its mass. He did not perform any trials for this scenario, and he was not able to form a good quality hypothesis. He identified only the dependent variable, but offered no explanation. For the third scenario, the student was unable to correctly identify which liquid would have greater mass. He made the same incorrect answer after the experiment. However, he was able to identify the correct variables that would impact the relationship.

Microworld 3: Archimedes Results

For the first scenario in the final microworld, student two correctly identified that an object's orientation does not affect displacement. He suggested that as long as there was a top on the container, the volume would stay it in not matter what direction the top was facing. Student two conducted seven trials. The second trial was a duplicate of the first, and the third changed only the type of liquid to oil. The fourth trial showed a change in every variable besides liquid type (oil). The next trial, however, the student changed only the object's orientation (horizontal). The sixth, he changed the orientation back (vertical), and changed the liquid type (water). Finally, he changed the orientation (horizontal) while keeping the other variable constant. This demonstrates that, with more trials, the student was able to hone in on the target variable, orientation. He left the conclusion section blank.

For the second scenario on type of liquid, the student correctly identified that liquid type will affect displacement; however, he did not offer a hypothesis. Rather, he gave rationale for his answer through an example. Student two conducted six trials. The first two trials, he changed only liquid type. The third trial, he increased mass, keeping the other variables constant. He then increased the object volume in the fourth trial. In the fifth trial he changed orientation, and then he tested object mass in his sixth. In all of these trials, he was using the control for variables strategy. He was not, however, conducting an experiment to test for liquid type. After experimentation, his conclusion was that an object floats differently given a different position; this may be a result of student two misunderstanding the concept of displacement, instead relying on amount submerged.

For the final scenario in this microworld, the student explained that he was basing his prediction on data analysis. Student two conducted four trials. He did not change the object's orientation, which relates to the earlier experimentation on that variable's impact on displacement. From the first to the second trial, he increased only mass. He then repeated this again, decreasing then increasing mass. This shows that this student is aware that orientation does not impact displacement, knows what mass does, but is unclear about the other variables. Once again, he left the conclusion sections after the experiment blank.

Overall, the trial data for student two demonstrates a good ability to use a control for variables strategy. The excessive trials involving changing multiple different variables shows that he perhaps found it difficult to focus on the testing the hypothesis by changing only the target variable. This can also be seen in the fact that he left the majority of the conclusion sections blank.

Post: Combination Sink/Float Results

Student two was able to correctly identify all combinations.

Student Three

Background Information

Student three is a male thirteen year old in the eighth grade. In the background survey it was revealed that his favorite classes in school are math and science; he usually finds learning science easy, and enjoys science sometimes. He states that his grades are consistently in the "A" range. He is unsure about his parents' highest degrees of education.

Inquiry Pretest Results

Student three scored an overall 53.33% on the inquiry pretest. On the first pretest question (63802), he was unable to identify the independent variable or the dependent variable. On the second question (63803), he was able to identify the independent variable, and correctly complete the hypothesis. On the third question (63989), he was able to identify the dependent variable before the test, but not the independent; he was unable to correctly identify the dependent after the test. On question four, when asked to how he would go about conducting an experiment (29462), he chose the incorrect option to keep some variable constant, and change other variables, especially the variable you are testing. On the fifth question (29464), he was able to correctly determine how to make the swing go faster. His explanation awarded him only partial credit. While he was able to identify the independent and dependent variables, he said that he chose his answer based on experience with the situation. For the sixth, seventh and eighth questions he was consistently able to answer the questions regarding the control for variables strategy.

Overall, student three's answers to the questions in the inquiry pretest demonstrate a good skill at using the control for variables strategy. His reasoning in the open response question hints that he may be relying on prior knowledge or experience to answer, as opposed to inquiry reasoning. He was able to identify the independent and dependent variables sometimes. He was able to complete the hypothesis, which may indicate his ability to recognize the relationship between independent and dependent variables, as well as the purpose of a hypothesis.

Knowledge Pretest Results

Student three scored an overall 28.57% on the knowledge pretest. Student three was not able to correctly choose the box that held the most cereal, but he was able to correctly identify which could hold the most volume. This is a strange result, since a student who does not understand the concept of volume would most likely correctly answer the first question and get the second question wrong, not vice versa. Given this, it is possible that the student accidently wrote the wrong answer for the first part of the question, or that he guessed on the second. On the second question (62958,) he was unable to identify which stack had the largest volume, but was able to tell which had the larger mass. He was unable to correctly answer the questions regarding density. Because he chose that a certain cereal had the largest density in the mystery cereal question, it shows that he was not aware that density is a property of material. This is echoed in the fact that his response to what additional information is required to determine which cereal box has the higher density was simply to test them. These results demonstrate that student three somewhat has an understanding of mass and volume, but a very partial comprehension of density.

Microworld 1: Volume Exploration Results

Student three was unable to correctly identify the container that held the most volume in question 63990. His hypothesis identified the dependent variable, but incorrectly identified the independent. His response, however, identified a strong relationship between the variables he suggested. After experimenting with the microworld, he was able to confirm his initial answer to identify the container that held the most volume; he was able to answer this correctly for the concept question, but was still unable to correctly choose for the terminology question. This demonstrates that he was able to conceptually understand the idea of volume after the microworld, however, was still unable to connect it to the term.

Microworld 2: Density Balance Results

Student three started the density balance microworld with the first scenario on shape by incorrectly believing that the shape of a container affects the mass of the liquid if holds. Student three conducted only one trial. In this trial, he kept both sides exactly the same, including container shape (width). Thus, he did not conduct an experiment to test his hypothesis. After experimenting, he did not change his original conception, offering no explanation. For the second scenario, he answered incorrectly that liquid type will not affect its mass. Again he conducted only one trial, but kept all variables constant, changing only the type of liquid on both sides. This demonstrates that student three was able to implement a control for variables strategy for this exploration. After experimenting, his was unable to form a hypothesis; rather, he attempted to create a hypothesis by offering a solid definition of mass, but was unable to relate it to the problem at hand. For the third scenario, he was able to correctly identify which liquid would have the greater mass. His conclusion after the experiment strongly confirmed this; unlike his other responses, student three gave an in depth, correct explanation for this question, which offered examples to confirm his answer.

Microworld 3: Archimedes Results

For the first scenario in the final microworld, student three correctly identified that an object's orientation does not affect displacement. He offered a strong explanation and identified a relationship, but did not do so in hypothesis form. Student three conducted four trials. While all four trials did not use a control of variables strategy to isolate the target variable, this student was able to correctly identify which ones did and draw the correct conclusion. After experimentation, he was able to confirm his initial belief, but did not offer an in depth explanation. For the second scenario on type of liquid, he incorrectly identified that liquid type will not affect displacement, without offering any explanation as to why. This student conducted three trials changing only the object's mass. After experimentation, he still held on to his original notion, again without explanation. For the final scenario in this microworld, he explained that he was basing his prediction on how much volume the object has; while this was not the expected answer, he identified one variable that would impact whether or not an object would float or sink in his response. Student three did not conduct any trials, but he was able to conclude that volume and mass both impacted whether or not an object would sink or float.

In general, the trial data shows that student three was not able to consistently use a control for variables strategy to conduct his experiments. His data suggests that he found it difficult to relate the question at hand to a set of variables for experimentation; this is revealed in a lack of trials, as well as trials isolating the target variable.

Post: Combination Sink/Float Results

Student three was able to correctly identify all combinations except the second combination (Lead Ball/Rubbing Alcohol) and the fifth combination (Maple Wood Ball/Rubbing Alcohol). Given that these were both in rubbing alcohol, it may suggest that student three is confused by that substance; however he was able to correctly choose for the rubber ball/rubbing alcohol combination in question eight.

Student Four

Background Information

Student Four is a thirteen year old female. She said that history and math are her favorite subjects in school. She noted that she finds science class somewhat easy; however she remained neutral about liking or disliking learning science. She also stated that she receives mostly B’s overall in school and mostly B’s in science classes.

Inquiry Pretest Results

Overall, student four scored 33.33% in the inquiry pretest. In inquiry pretest 1 (63802), she was unable to correctly identify the independent and dependent variables. For both she chose the mass of the wagon as the answer. In inquiry pretest 2 (63803), she correctly identified the independent variable in the hypothesis, but she incorrectly chose the size of the candy bar as the dependent variable. Similarly in inquiry pretest 3(63989), student four correctly identified the independent variable, but was not able to identify the correct dependent variable before she was given the experiment results. In her response to inquiry pretest 4 (29462), she incorrectly chose the potential hypothesis for Homer's experiment to be, "You should keep some of the variables the same and change the other variables, especially the variables you are testing". In inquiry pretest 5 (29464), she chose the incorrect variable, using a less massive tire, to make the tire swing go faster. However, she did go on to describe her reasoning well enough to earn half credit (3/6 points). She stated "because if you use a less massive tire its less weight on the string and the string can move a bit faster". In inquiry pretest 6 (29465) and inquiry pretest 7 (45720), she did not answer the questions about variables in the experiments correctly, but in inquiry pretest 8 (45721) she was able to choose the correct situation to test the hypothesis.

The majority of responses from student four reflect that she has a basic understanding of independent variables, but that she does not understand dependent variables or the control for variables strategy. Her answers were relatively consistent, demonstrating that she has a stronger ability in identifying the variable being changed, but a weaker ability in creating and testing a hypothesis. She was able to create a solid, yet incorrect, hypothesis for one question, but this demonstrated her use of prior knowledge and reasoning rather than the analysis of experimental data. Overall, she did not have a strong background in developing and testing hypotheses.

Knowledge Pretest Results

In this portion of the pretests, student four scored an overall 71.43%. She answered both questions in knowledge pretest 1 (62956) and part 1 of knowledge pretest 2 (62958) correctly, which demonstrates her understanding of volume. She answered part 2 of knowledge pretest 2 incorrectly by choosing stack A to have the larger mass, indicating her lack of understanding of mass. Then, she incorrectly chose stack B to have the greatest density in part 3. In knowledge pretest 3 (62961), she was able to correctly answer that not enough information was given to know the density, and then responded that the weight and how tall each container is was needed to determine the density. This section revealed that student four may not have a good understanding of mass, but does understand weight and density in terms of weight, not mass.

Microworld 1: Volume Exploration Results

In parts 1 and 2 of the volume exploration microworld, student four did not choose the correct container or create a hypothesis, but she was able to create a statement explaining her reasoning that demonstrated a relationship between the size of the containers and its volume. In parts 3 and 4 after the experiment, she was again able to correctly identify which container had the most water in it and which had the largest volume. This confirmed her strength in the topic of volume.

Microworld 2: Density Balance Results

In the first density balance (64326) microworld, student four correctly identified that shape does not affect the mass of the liquid. However, similar to her response in the volume microworld, she was not able to make a hypothesis. She gave a description of the containers she saw, but was not able to give a relationship. She performed one trial of experimentation, in which she kept all variables the same except for the shape of the container. This trial correctly tested her response to the question; however, she did not perform another trial in which the containers were the same in order to compare results. In density balance part 2 (62950), she correctly answered that the type of liquid will affect its mass and gave a complete hypothesis demonstrating a relationship between type of liquid and its mass. When asked to conduct an experiment that would test if the type of liquid affects mass, she conducted two identical trials. In the trials she did not change the type of liquid; therefore she did not correctly use control of variables strategy. She was able to identify oil as having the largest volume after the experiment, but chose to say that the relationship is the same between the type of liquid and its mass. She did not earn any points for relationship or quality; however, the ambiguity of the question and possible answers could have been cause for her error.

Microworld 3: Archimedes Results

In Archimedes part 1 (62951), student four did not receive any credit. She did not show any understanding of the effect or lack of effect an object's orientation had on its mass, and was not able to create hypotheses. In her answers, she related orientation to pressure and reasoned that objects can change liquids' densities when dropped into them. In the experiment, she conducted two trials. In the second trial, she changed the object's mass, orientation, and volume. She was testing the correct variables but did not correctly employ a control of variables strategy. In Part 2

(62952) of the Archimedes experiment, student four was able to create a hypothesis about the relationship between type of liquid and displacement. She earned 4/5 points and received half credit on her explanation of how displacement is affected by different liquids. In the experiment, student four conducted three trials. Between trials one and two she varied object orientation and liquid type, and between trials 1 and 3 she varied only liquid type. She was able to isolate the variables she was asked to test, and correctly used the control of variables strategy. Student four did not receive any credit for part 3 (62953). She did not perform the experiment and responded that she did not change any variables. This microworld showed student four's lack of understanding of density and displacement. It also clearly illustrated her weaknesses in understanding the control for variables strategy and writing hypotheses.

Overall, student four did not have a strong understanding of experimenting using the control for variables strategy. However, by the third experiment she was able to correctly isolate variables, which demonstrated her progress in testing based on the question. The lack of trials illustrates her weakness, as well as the possibility that she may not have put her full effort into the task.

Post: Combination Sink/Float Results

Student four answered two combinations correctly. She did not understand the relationship between the given densities, and could have possibly been guessing throughout the posttest.

Student Five

Background Information

Student five is a fourteen year old male. His favorite subjects in school are math, english, and reading. He noted that he finds science class somewhat easy; however he remained neutral about liking or disliking learning science. He also stated that he receives mostly B's overall in school and mostly B's in science classes.

Inquiry Pretest Results

Student five scored an overall 53.33% on the inquiry pretest. He correctly identified the independent and dependent variables in pretests 1 (63802) and 2 (63803). However in pretest 3 (63989), he was not able to correctly identify the independent or dependent variables, even after the results of the experiment were given. He did choose the correct option for a hypothesis in pretest 4 (29462). In inquiry pretest 5 (29464), he chose the incorrect variable, using a less massive tire, to make the tire swing go faster. He goes on to describe his reasoning well enough to earn half credit (3/6 points). He stated that "because if the tire has more weight to it, it will move at a slow speed, but if the tire has less weight, it will move quicker". He was not able to choose the correct variable in pretest 6 (29465), but was able to answer correctly for pretests 7 (45720) and 8 (45721).

The results for the inquiry pretest for student five were slightly inconsistent. In most areas he showed a moderate understanding of independent and dependent variables, and a strong understanding of hypotheses and control for variables strategy. He did show a small reliance on prior knowledge instead of analyzing the data presented in experiment in pretest 5. However, he was still able to develop a hypothesis. He lost most of his points in the identification of independent variables, but earned a significant amount of his points in the open response sections.

Knowledge Pretest Results

In the knowledge pretest, student five received an overall score of 57.14%. He was able to identify which box could hold the most cereal in pretest 1 (62956), but did not choose the same, and correct, answer for which box has the largest volume. In pretest 2 (62958), he was able to identify the box with the greatest volume, but then guessed boxes for greatest mass and density. When prompted in pretest 3 (62961), he responded correctly that there was not enough information and the weight of the cereal was necessary.

Student five's answers were slightly inconsistent in the Knowledge Pretest, but they did show that he had a moderate understanding of volume and at least weight in the relationship of density; however, he also showed some misconceptions regarding size and mass.

Microworld 1: Volume Exploration Results

In parts 1 and 2 of the volume exploration microworld, student five chose the correct answer and created a statement that clearly explained his reasoning and demonstrated a relationship between the size of the containers and its volume. Unfortunately, he could not earn full points because he did not actually create a hypothesis. In parts 3 and 4 after the experiment, he was again able to correctly identify which container had the most water in it and which had the largest volume. This portion of the microworld illustrated student five's good understanding of volume.

Microworld 2: Density Balance Results

In the first part of the density balance (64326) microworld, student five answered incorrectly that the shape of the container affects the mass of the liquid, but after the experiment earned full credit when he was able to correctly identify and explain the relationship between shape of the container and mass of the liquid. He performed three trials to test his response. In trial two he changed only liquid type from trial one, but in trial three he only changed container shape from trial one. These trials used the control for variables strategy and were successful in demonstrating the correct results to the student. In density balance 2 (62950), he incorrectly answered that the type of liquid will not affect its mass and gave an explanation that mass depends on the container instead of a writing a complete hypothesis and explaining the relationship between type of liquid and its mass. He did not conduct any trials in the microworld. He was able to identify that oil had the largest volume. When he was asked to say something about the relationship between the type of liquid and its mass, he just described an example and said that the mass of oil is less than the mass of water. He did not demonstrate an understanding of the topic, but was at least able to specify a relationship between the type of liquid and its mass.

Microworld 3: Archimedes Results

In the final microworld Archimedes part 1(62951), student five demonstrated a good understanding of the relationship between object orientation and displacement, although he did not form an actual hypothesis. He performed three trials to test orientation and displacement. After trial one, he changed the object's mass and orientation in trial two. In trial three he only changed the liquid type compared to trial two. These trials show that he was experimenting with the correct variables, but did completely individually isolate the variables he wished to test in a correct control for variables strategy. When asked to look at the data and relate orientation and displacement, he related the sinking and floating of an object in terms of density, instead of describing the effect of its orientation. In Archimedes part 2 (62952), he guessed incorrectly that the type of liquid will not affect displacement and did not give a hypothesis. He was only able to earn 1/5 points for that question. In this microworld experiment he performed two trials. He changed every variable in the second trial, which means he did not use the control of variables strategy. His changes may indicate he was just playing with the microworld, rather than using it to experiment. After the experiment, he was able to correctly answer and describe how displacement is affected by different types of liquids by stating "if the liquid is thick like the oil then it will be hard for the block to sink because the oil has a high density". In Archimedes 3 (62953), student five repeatedly focused on mass instead of on the relationship between type of liquid or orientation. He conducted five trials in the experiment, altering only one variable each time. From trial one to trial two he changed the object mass, from trial two to trial three he changed the liquid type, from trial three to trial four he changed orientation, and from trial four to trial five he changed the object's mass again. This was the most thorough experimentation student five conducted. It was a great example of isolating variables. In the final question, he earned 1/3 possible points for variables that would affect sinking and floating.

In general, student five demonstrated a moderate skill level and understanding of testing a hypothesis using the control for variables strategy. For the majority of his experiments, he was able to keep irrelevant variables constant and compare individual results of the independent variables. He also did not conduct excessive trials.

Post: Combination Sink/Float Results

Student Five answered all combinations correctly.

Student Six

Background Information

Student six is a thirteen year old male. He said that history and math are his favorite subjects in school. He noted that he finds science class usually easy and enjoys learning science at all times. He also stated that he receives mostly A's overall in school and mostly B's in science classes. He said that the highest level of education in his household is a PhD/post grad degree.

Inquiry Pretest Results

Overall, student six scored 40% on the Inquiry Pretest. In pretests 1 (63802) and 2 (63803), he was only able to identify the first dependent variable. While in pretest 3 (63989) he was not able to correctly identify the dependent variable, he was able to identify the independent variable. After the results of the experiment were given, he was still not able to identify the dependent variable or make a correct hypothesis. He did choose the correct option for a hypothesis in pretest 4 (29462). In inquiry pretest 5 (29464), he chose the incorrect variable, using a longer rope, to make the tire swing go faster. He was able to recognize that the length of the rope affected the speed, but he interpreted the data incorrectly. In pretest 6 (29465), he chose the correct procedure for testing the vaccine and in pretest and 8 (45721), he chose the correct situation to test the seeds. In pretest 6 (45720), he was not sure which plant to choose in order to use the correct control of variables strategy.

The results for the inquiry pretest for student six showed that he consistently showed a weakness in identifying variables; however, he was still able to make solid hypotheses.

Knowledge Pretest Results

In the knowledge pretest, student six received an overall score of 71.43%. He was able to identify which box could hold the most cereal, and knew that that was the box with the greatest volume in pretest 1 (62956). In pretest 2 (62958), he incorrectly guessed that the stacks of boxes had the same volume, but did correctly identify the stack with the greater mass. When asked to identify the stack with the greater density, he guessed incorrectly. However, if the answer was based off of his previous answer, he would have been correct. This showed that he may have had a problem identifying the volume, but still understood the relationship between volume and mass in density. In pretest 3 (62961), he responded correctly that there was not enough information and that the mass of the cereal was necessary.

In this part of the pretest, student six revealed he had a solid understanding of density and the relationship between mass and volume. He had a couple inconsistencies in his answers, but overall he demonstrated the knowledge and skills to relate to the concepts presented in the pretest.

Microworld 1: Volume Exploration Results

In parts 1 and 2 of the volume exploration microworld, student six chose the correct answer and created a statement that explained his reasoning and demonstrated a relationship between the size of the container and its volume. The statement was not the requested hypothesis, and it did not contain a clear dependent variable. Instead of relating size to volume, student six said that the size was proportional to how much density could be contained. In parts 3 and 4 after the experiment, he was able to correctly identify which container had the most water in it and which had the largest volume. In this first microworld, student six again demonstrated some weakness in dealing with variables, but still had a basic understanding of the questions, especially after the experiment.

Microworld 2: Density Balance Results

In density balance 1 (64326), student six answered correctly that the shape of the container does not affect the mass of the liquid. He then conducted four experiments to test his hypothesis. Trial one used the initial conditions set in the microworld. For trials two through four, he changed the liquid type to oil, but only changed container size between the three trials. The trials successfully and concisely tested his hypothesis using the control for variables strategy. He earned 3/4 possible points for his conclusion on this relationship. In density balance 2 (62950), he also answered correctly that the type of liquid will affect its mass, and earned 6/8 points for his hypothesis. He lost two points in the quality of his hypothesis and explanation. In the microworld he conducted two trials. In the first trial, both sides contained oil and in the second trial, he changed one side to water. Once again, he correctly employed the control of variables strategy.

He only changed the variable that he was testing and did not perform excessive trials. He did not correctly identify oil as having the largest volume, but was still able to earn 3/4 points for his explanation of the relationship between types of liquid and mass. This microworld illustrated student six's strength in the content knowledge of density, and also his slight weakness in developing full hypotheses and explanations.

Microworld 3: Archimedes Results

In Archimedes part 1 (62951), student six correctly answered that flipping or rotating an object will not affect displacement. He earned 3/4 points for his explanation. He conducted eleven trials for this part of the microworld; however, he indicated that he used CVS in trials 4-10. From trial four through ten, he only changed one variable. He alternated between changing the object mass, orientation, volume, and liquid type. Again, his experiments illustrated a good understanding of testing a hypothesis using control for variables strategy. After the experiment he changed his mind, and incorrectly answered that the orientation has an effect on the amount of liquid displaced. This change could be a misunderstanding due to the change in wording, or that the experiment was not conducted using the correct control for variables strategy. In Archimedes part 2 (62952), he correctly hypothesizes that the type of liquid affects displacement. He conducted a total of eleven trials, but indicated that trials one through eight were the most important. The trial results show that he compared every two trials, changing the object mass, orientation, and volume incrementally throughout the trials. Trials one and two had the same values, only the type of liquid was changed. Trials three and four differed slightly from the previous two, but only differed from each other in liquid type. Trials five and six as well as trials seven and eight continued on in the same manner. This was a very thorough way to test the affect of liquid type on displacement. He demonstrated once again a strong skills for and understanding of experimentation. However, he later answers incorrectly that displacement stays the same and states that he is basing his answer off of prior knowledge. For the final experiment (62953), when asked what variables make an object float or sink, he selected the options mass of object and type of liquid. In his experiment, he conducted seven trials but indicated that trials three, four, five, and six were helpful. Between these trials he went through and only changed mass of object and liquid type. He kept all variables constant, except for one independent variable. At the end of this particular microworld, student six believed that the orientation has an effect on whether an object sinks or floats.

Overall, student six demonstrated a strong understanding of the control of variables strategy, and the ability to thoroughly test his hypothesis. He did conduct many trials, however it wasn't overly excessive and he identified which trials were most helpful. The amount of trials he conducted was necessary because he only changed one variable at a time.

Post: Combination Sink/Float Results

Student six chose all the correct combinations.

Student Seven

Background Information

Student seven is a fourteen year old male. The background survey revealed that his favorite subject in school is math and that he enjoys learning science and finds it to be somewhat easy.

However, his science grades are in the “B” range and his grades at school overall are in the “C” range. The highest level of education in his family/household is Bachelor’s/Undergraduate.

Inquiry Pretest Results

Student seven scored 66.67% on the inquiry pretest. On the first pretest question (63802), he was unable to identify the independent variable, but he was able to find the dependent variable. While on the second question (63803) the student was able to identify both the independent and dependent variable, he was unable to do so on the third question (63989). He was also not able to choose a valid hypothesis for the given experiment in question 63899. On question 29464, the student was able to make a conclusion based off of the given data. While on questions 29462, 45720 and 45721 he correctly identified how to test the given hypothesis, he was not able to do so on question 29465.

Overall, it can be found that when identifying variables, the student was stronger at identifying dependent variables than independent variables. However, he was not able to answer all questions regarding the identification of dependent variables correctly (out of the three questions, he correctly answered two). The student did not seem to know how to correctly create a hypothesis based off his answer to the one question that prompted him to do so. Despite the student’s inability to correctly form a hypothesis, out of the three questions regarding how to test hypotheses, the student answered three correctly. This shows that the student has a stronger grasp on how to test hypotheses once one is provided. The tire swing question (29464) showed that the student was able to analyze provided data to make a well-informed conclusion. On the following free-response question, the student was able to correctly mention the independent and dependent variables and the relationship between the two. However, his quality score suffered because he did not actually explain the reasoning behind his conclusion. Instead, he simply described the data that was provided in the table. This shows that the student may be able to identify independent and dependent variable, but may not be able to label them as such. This also may show that while the student can reason about conclusion, he is not able to provide a thorough written explanation supporting his conclusion.

Knowledge Pretest Results

Student seven scored an overall 85.71% on the knowledge pretest. Student seven was able to correctly answer all three questions about volume (62956 and 62958) indicating a strong grasp on both the definition and usage of volume. The student also answered the one question about mass (62958) correctly which shows that he also has a good base of knowledge about mass. On question 62961, student seven's response to the free-response question about density shows that he is aware of density as a concept as well as what information is needed to calculate density. However, his response to question 62958 demonstrated that the student still subscribed to certain misconceptions regarding density as he was not able to find that two boxes with different volumes and masses, but with the same material inside had the same density. While student seven may have some base knowledge about density, he may not understand all of its concepts.

Microworld 1: Volume Exploration Results

Student seven was able to correctly answer the three multiple-choice questions regarding volume (parts 1, 3, and 4) in question 63990. His answers showed that he had a strong grasp of the definition and usage of volume. His hypothesis about the relationship between size and volume was strong. In it, he correctly identified the independent variable, the dependent variable, and the relationship between the two. His hypothesis received full credit for quality as it did a good job of resembling the correct structure of a hypothesis as well as being specific in explaining his thoughts. After experimenting with the microworld, the student was able to confirm his initial answer to identify the container that held the most volume. In answering these questions correctly (both the concept question and the terminology question), he demonstrated that he understands the concept of volume.

Microworld 2: Density Balance Results

Student seven started the density balance microworld correctly answering the first question (64326) on the relationship between mass and shape of the container. During experimentation, student seven only performed one trial. However, in this one trial, the student was able to successfully isolate shape. After experimenting, he was able to make a conclusion that stated that there was no affecting relationship between the shape of the container and mass of the liquid. However, he did not expound upon what the relationship was or how one variable specifically impacted the other. For this reason, the student did not receive full credit on his answer. Nevertheless, his experimentation backed up his hypothesis and his conclusion.

For the second scenario, student seven answered correctly that liquid type will affect its mass. His hypothesis on the subject matter correctly identified the dependent and independent variables in question. However, his hypothesis did not have the proper hypothesis format and while his answer took into account that a relationship between mass and type of liquid existed, it did not explain the impact of the relationship. When analyzing the effect of the type of liquid on mass, student seven performed five trials changing only liquid type. The student's first three trials were identical and did not use different types of liquid. The last two trials were also identical to one another, but the student experimented with two different liquids in these trials. When picking which trials were helpful to his final conclusion, the student showed that he was knowledgeable about the control for variables strategy by picking a trial in which he used the same type of liquid and contrasting it with a trial in which he used two different types of liquids.

However, for the third scenario, after experimenting with the microworld, the student was unable to correctly identify which liquid would have greater volume given an equal mass. Moreover, in his conclusion after the experiment, he was once again unable to identify the correct impact of the relationship between type of liquid and it's mass. This confirmed that despite experimentation, while the student realized that a relationship existed between shape of container and liquid mass as well as between type of liquid and its mass, he was not able to form a written explanation as to why a relationship existed or how it worked.

Microworld 3: Archimedes Results

For the first scenario in the final microworld, student seven correctly identified that an object's orientation does not affect displacement. His response received full credit because it was structured like a hypothesis, and identified and elaborated upon the relationship between the orientation of an object and its displacement. In experimentation, student seven performed five trials. In these trials, student seven kept the same orientation throughout while manipulating volume and mass. While these variables were both manipulated, they were never done so at the same time. This shows that while the student may not have understood what variables to experiment with, he was aware of the control for variables strategy. This is supported by the fact that the student also correctly identified all of the trials that used a control for variables strategy. However, the student's difficulty in choosing the correct variables for experimentation mirrors his response in the post-experiment question in which the student did not identify the correct relationship and instead talked about mass and displacement. This may suggest that the student was not clear on what he was experimenting.

For the second scenario, he correctly identified that the liquid type does affect displacement. Once again, his response received full credit because it was structured like a hypothesis, and identified and elaborated upon the relationship between the type of liquid and its displacement. In experimentation, the student conducted six trials. In these trials, student seven correctly isolated liquid type (using the control for variables strategy) to see its effect on displacement. While the student was able to conclude after experimentation that water displaced more than oil, he made the incorrect reasoning that because water has more volume than oil, oil is able to float on top of water. Furthermore, when asked to identify the three possible variables that impact whether or not an object will sink, the student only mentioned one – mass. This suggests that the student understands that liquid type affects displacement (most likely through prior knowledge) but he does not have a correct or complete understanding of why or how.

Overall, student seven had a strong grasp on how to conduct an experiment to test a hypothesis and how to use the control for variables strategy in experimentation. Through his proper use of experimentation, the student collected all of the information necessary to reach the proper conclusions. However, at times, the student was not able to use the information to reach the correct relationship or explain how a relationship works.

Post: Combination Sink/Float Results

The only combination that student seven was not able to correctly identify was the combination with the maple wood ball and rubbing alcohol. This may be due to the fact that the densities were very close or that the student was confused with one or both of the materials presented in the combination.

Student Eight

Background Information

Student eight is a fourteen year old male. The background survey revealed that his favorite subjects in school are math science. He stated that he enjoys learning science and finds it to be usually easy. His grades in both science and other classes are consistently in the "A" range. The highest level of education in his family/household is PhD/Postgraduate.

Inquiry Pretest Results

Student eight scored 66.67% on the inquiry pretest. On the pretest questions in which the objective was to identify the dependent and independent variables (questions 63802, 63803, and 63989), the student was never able to correctly identify the dependent variable and only correctly identified the independent variable once. When it came to hypotheses, on question 63989, he was able to choose a valid hypothesis for the given experiment. However, he correctly answered only half of the questions regarding how to test hypotheses (questions 29462, 29465, 45720, and 45721). On question 29464, he was able to make a conclusion based off of given data.
Overall, it can be found that given a situation, the student is not able to correctly identify the independent and dependent variables. Since in the student's answer to the free-response question

(29464) he correctly mentioned both the independent and dependent variables, this may mean while the student is aware of the two different variables, he is not able to label them correctly by name. The student realized what a correct hypothesis looked like and how to formulate one. However, once a hypothesis was found, the student was not always sure how to test it. When the student was given data and a particular situation, he showed the ability to analyze the data and create a conclusion based off of the data. He was also able to create a well-written explanation that showed how he reached his conclusion. On his free-response answer (29464), the student received full marks, as he correctly mentioned both the independent and dependent variables, the relationship between them, and also because his explanation was clear and not only referenced the data, but also showed how a conclusion could be made off of the data. The student's response shows that (given a particular situation with data) his reasoning and explanation skills are good.

Knowledge Pretest Results

Student eight scored an overall 85.71% on the knowledge pretest. Student eight was able to correctly answer all three questions about volume (62956 and 62958) indicating a strong grasp on both the definition and usage of volume. The student also answered the one question about mass (62958) correctly which shows that he also has a good base of knowledge about mass. On question 62961, student eight's response to the free-response question about density shows that he is aware of density as well as what other components are needed to calculate density. However, his response to question 62958 demonstrated that the student still subscribed to certain misconceptions regarding density as he was not able to find that two boxes with different volumes and masses, but with the same material inside had the same density. While student eight may have some base knowledge about density, he may not fully understand the whole concept.

Microworld 1: Volume Exploration Results

Student eight was able to correctly answer the three multiple-choice questions regarding volume (parts 1, 3, and 4) in question 63990. His answers showed that he had a strong grasp of the definition and usage of volume. His hypothesis about the relationship between size and volume was strong. In it, he correctly identified the independent variable, the dependent variable, and the relationship between the two. His hypothesis received full credit for quality as it did a good job of resembling the correct structure of a hypothesis as well as being specific in explaining his thoughts. After experimenting with the microworld, the student was able to confirm his initial answer to identify the container that held the most volume. In answering these questions correctly (both the concept question and the terminology question), he demonstrated that he understands the concept of volume.

Microworld 2: Density Balance Results

Student eight started the density balance microworld by correctly answering the first question (64326) on the relationship between mass and shape of the container. During experimentation, student eight performed six trials. While the first two trials were identical, in the later trials the student was able to successfully isolate shape. After experimenting, he was able to make a conclusion that stated that there was no relationship between the shape of the container and the mass of the liquid. However, he did not expound upon what the relationship was or how one variable specifically impacted the other. For this reason, the student did not receive full credit on his answer.

For the second scenario, student eight answered correctly that liquid type will affect mass. His hypothesis on the subject matter correctly identified the dependent variable, the independent variable, and the relationship between them. However, his hypothesis did not have the proper hypothesis format. When analyzing the effect of the type of liquid on mass, student seven performed two trials. These two trials correctly isolated liquid type. When picking which trials were helpful to his final conclusion, the student showed that he was knowledgeable about the control for variables strategy by picking a trial in which he used two different types of liquids.

For the third scenario, after experimenting with the microworld, the student was able to correctly identify which liquid would have the greater volume given an equal mass. Moreover, in his conclusion after the experiment, he was once again able to identify the correct impact of the relationship between type of liquid and it’s mass. This confirmed that while the student had prior knowledge regarding the relationships between shape of container and liquid mass as well as between type of liquid and its mass, experimentation allowed him to further cement his knowledge.

Microworld 3: Archimedes Results

For the first scenario in the final microworld, student eight correctly identified that an object’s orientation does not affect displacement. His response did not receive full credit because it was not structured like a hypothesis nor did it identify and elaborate upon the relationship between the orientation of an object and its displacement. In experimentation, student eight performed two trials. In these trials, student seven tested orientation, but since he also manipulated object mass and object volume, he did not correctly isolate orientation. This shows that the student may not have understood what variables to experiment with. The student's difficulty in choosing the correct variables for experimentation mirror the response in the post-experiment question in which the student did not identify the correct relationship and instead talked about density and orientation. This may suggest that the student was not clear on what he was experimenting or on what his results meant.

For the second scenario, he correctly identified that the liquid type does affect displacement. His response received full credit because it was structured like a hypothesis, and identified and elaborated upon the relationship between the type of liquid and its displacement. In experimentation, the student conducted six trials. In these trials, student eight separately manipulated all of the given variables (using the control for variables strategy) to see its effect on displacement. Since after experimentation, the student was able to reiterate his correct hypothesis and support it with data from the experiment, the fact that the student did not just isolate liquid type suggests that he was simply checking all other options before reaching his final conclusion. Furthermore, he showed an understanding that it is the different densities of the different liquids that truly affect the displacement. When asked to identify the three possible variables that impact whether or not an object will sink, the student mentioned all three. This suggests that the student understands that liquid type affects displacement and that his understanding is scientific as he is knowledgeable about why and how this relationship works.

Overall, student eight had a strong grasp on how to conduct an experiment to test a hypothesis and how to use the control for variables strategy in experimentation. Through his proper use of experimentation, the student collected all of the information necessary to reach the proper conclusions. With this information, the student was able to reach the correct relationship between variables or explain how a tested relationship works. Student eight did not waste any of his trials, which shows that he was aware for the most part of what he was testing and what types of conclusions he was looking for.

Post: Combination Sink/Float Results

Student eight was able to correctly identify all combinations.

Student Nine

Background Information

Student nine is a thirteen year old male. The background survey revealed that his favorite subjects in school are English and social studies. He stated that sometimes he doesn't enjoy learning science and that he finds science class difficult. However, both his science grades and his overall grades are in the "B" range. The highest level of education in his family/household is High School.

Inquiry Pretest Results

Student nine scored 60% on the inquiry pretest. On the pretest question in which the objective was to identify the dependent and independent variables (questions 63802, 63803, 63989) the student was never able to correctly identify the dependent variable two out of three times and the independent variable two out of three times as well. When it came to hypotheses, on question 63989, the student was not able to choose a valid hypothesis for the given experiment. However, he correctly answered half of the questions regarding how to test hypotheses (questions 29462, 29465, 45720, and 45721) given an actual hypothesis. On question 29464, the student showed that he was not able to make a conclusion based off of given data.

Overall, it can be found that the given a situation, the student is able to correctly identify the independent and dependent variables most of the time. This is supported in the student's answer to the free-response question (29464) where he correctly mentioned both the independent and dependent variables. The student was not able to understand what a correct hypothesis looked like or how to formulate one. Also, once a hypothesis was found, the student was not always sure how to test it. When the student was given data and a particular situation, he was not able to correctly analyze the data in order to create a well-informed conclusion based off of the data. While he did not ultimately reach the correct conclusion based off the data, his free-response answer (29464) showed that he was able to correctly identify the independent and dependent variables. However, in this case, he was not able to find the correct relationship between the two, which may mean that while the student can identify the necessary data, he is not able to use it to correctly analyze it. This may show that the student's reasoning skills are low. Despite his reasoning skills, the student showed the ability to formulate a well-written explanation. Although the explanation did contain incorrect reasoning, it did have the correct structure for an explanation complete with both scientific reasoning and data analysis.

Knowledge Pretest Results

Student nine scored an overall 85.71% on the knowledge pretest. Student nine was able to correctly answer all three questions about volume (62956 and 62958) indicating a strong grasp on both the definition and usage of volume. The student also answered the one question about mass (62958) correctly which shows that he also has a good base of knowledge about mass. On question 62961, student nine's response to the free-response question about density shows that he is aware of density as well as what information is needed to calculate density. However, his response to question 62958 demonstrated that the student still subscribed to certain misconceptions regarding density as he was not able to find that two boxes with different volumes and masses, but with the same material inside had the same density. While student nine may have some base knowledge about density, he may not fully understand the whole concept.

Microworld 1: Volume Exploration Results

Student nine was able to correctly answer two out of the three multiple-choice questions regarding volume (parts 3 and 4) in question 63990. Although his answer to part 1 was incorrect, in his answer to the free-response question about the relationship between size and volume he wrote that he had meant to choose the correct answer in part 1. In his hypothesis about the relationship between size and volume, he correctly identified the independent variable, the dependent variable, and the relationship between the two. However, his hypothesis did not receive full credit for quality as it more resembled an explanation and data description rather than a hypothesis. Overall, the student's answers in this microworld demonstrated that he understands the concept of volume.

Microworld 2: Density Balance Results

Student nine started the density balance microworld incorrectly answering the first question (64326) on the relationship between mass and shape of the container. During experimentation, student nine performed two trials. In these trials, the student incorrectly manipulated liquid type instead of container shape. His confusion in what variable to manipulate is shown even after experimenting as he was still not able to conclude on the correct relationship between the shape of the container and mass of the liquid.

For the second scenario, student nine answered correctly that liquid type will affect mass. His hypothesis on the subject matter correctly identified the dependent and independent variables in question. However, his hypothesis did not have the proper hypothesis format and while his answer did take into account that a relationship between mass and type of liquid existed, he did not explain the impact of the relationship. When analyzing the effect of the type of liquid on mass, student nine performed only one trial. This trial did not correctly isolate liquid type. When picking which trials were helpful to his final conclusion, the student picked a trial number that he did not even test. Since the student's hypothesis was correct, this may mean that the student has some prior knowledge on this topic, but he is not sure how to experiment with it.

For the third scenario, after experimenting with the microworld, the student was able to correctly identify which liquid would have greater volume given an equal mass. However, in his conclusion after the experiment, he was once again unable to identify the correct impact of the relationship between type of liquid and it’s mass. This confirmed that despite experimentation, while the student realized that a relationship existed between shape of container and liquid mass as well as between type of liquid and its mass, he was not able to form a written explanation as to why a relationship existed or how it worked.

Microworld 3: Archimedes Results

For the first scenario in the final microworld, student nine correctly identified that an object's orientation does not affect displacement. His response did not receive full credit because it was not structured like a hypothesis nor did it identify and elaborate upon the relationship between the orientation of an object and its displacement. In experimentation, student nine performed eight trials. In these trials, student nine tested orientation, but since he also manipulated object mass and object volume, he did not correctly isolate orientation. This shows that the student may not have understood what variables to experiment with. The student's difficulty in choosing the correct variables for experimentation mirrors his response in the post-experiment question in which the student did not identify the correct relationship and instead said that orientation did not affect the volume a lot, which may mean that the student does think that the orientation of an object affects displacement. This difference in the pre- and post-experimentation answers may be due to the fact that in the first question the words "flipping" and "rotating" were used while in the second question "displacement" was used. Even though the term displacement was defined, it may be possible that the student still did not understand its meaning and therefore was not able to correctly answer the question.

For the second scenario, he correctly identified that the liquid type does affect displacement. Once again, his response did not receive full credit because it was not structured like a hypothesis nor did it identify and elaborate upon the relationship between the type of a liquid and the displacement. In experimentation, the student conducted five trials. In these trials, student nine correctly isolated liquid type (using the control for variables strategy) to see its effect on displacement. However, after experimentation, while the student knew that an object may sink in both oil and water, he did not mention if there would be any difference in the displacement between the two. Furthermore, when asked to identify the three possible variables that impact whether or not an object will sink, the student only mentioned one – type of liquid. This suggests that the student understand that liquid type affects displacement (most likely through prior knowledge) but he does not have a correct or complete understanding of why or how.

Overall, student nine did not have a good grasp on how to conduct an experiment to test a hypothesis and how to use the control for variables strategy in experimentation. Though he did manage through experimentation to eventually collect all of the information necessary to reach the proper conclusions, the student was not able to use the information to reach the correct relationship or explain how a relationship works. His high inquiry and knowledge pretest scores show that this student is aware of experimentation and has good background knowledge of the concepts presented, so it may be that the concept of experimentation or how experimentation was presented in the microworld was confusing to the student. Also, while working on the microworlds, the student worked at a slow and steady pace using more time to think concepts out. Therefore, the time constraint and the peer pressure of others finishing earlier than him, may have led this student to not give himself enough time to think out what he was doing.

Post: Combination Sink/Float Results

Student nine was able to correctly identify all combinations except for the first combination (Lead Ball / Salt Water) and the second combination (Lead Ball / Rubbing Alcohol). Given that both of these combinations contained the lead ball, it may suggest that the student was confused by that material. However, he was able to correctly choose for the lead ball / liquid mercury combination in question three.

Table 4. Analysis of Students' Inquiry Processes within the microworld

Student	Inquiry Scores without open response	Knowledge Scores	Trials where CVS was used (% of trials)	Trials where a IV was changed (% of trials)	Both CVS used and IV was tested (% of trials)
Student 1	45.5%	85.7%	100.00	83.33	83.33
Student 2	27.3%	85.7%	77.78	61.11	33.33
Student 3	54.5%	28.6%	37.50	87.50	25.00
Student 4	27.3%	71.4%	50.00	25.00	12.50
Student 5	63.6%	57.1%	54.55	63.64	27.27
Student 6	36.4%	71.4%	66.67	75.76	45.45
Student 7	63.6%	85.7%	100.00	50.00	50.00
Student 8	45.5%	85.7%	80.95	42.86	28.57
Student 9	54.5%	85.7%	86.67	53.33	26.67
Average	46.5%	79.1%	72.68%	60.28%	36.90%

We also wanted to see if the results from the Inquiry and knowledge pretests would predict a student's performance inside of the microworlds. For example would a student with high inquiry knowledge and high content knowledge, as indicated by the pre-tests, consistently perform experiments using the indicated independent variable and controlling for variable strategy? What about a student with low inquiry and high content knowledge? During analysis we looked at how often the student used CVS, how often they correctly tested their stated hypothesis, and whether they consistently interpreted their data correctly. While all but one student used CVS on more than 50% of their trials, they often changed the variables they were testing, for example a student might first run a trial testing his/her independent variable but then on the next trial switch to some other variable that they did not indicate as an independent variable. Rarely did we see a student run experiments where they tested the same independent variable consecutively in an experiment without changing the other variables in between trials. Instead we saw experiments like this, in which they tested a different variable on each trial as seen in the following table.

Table 5. Example of Students' Experimental Trials

Trial 1	Trial 2	Trial 3	Trial 4
Orientation of Object	Type of Liquid	Mass of Object	Object Volume

Student One Assistment 62952

It seems that even if students understood the concept of CVS and IV manipulation, this student's actual use of these concepts across experiments varies. While student one used CVS on all of his trials, other students would sometimes change multiple variables within a trial and then switch back to using CVS on the next trial.

The first was student one who we marked as low inquiry, high knowledge; he performed the best in the microworld setting. He used CVS on every trial and correctly tested the target Independent variable 83.33% of the time. This led to 83.33% of the trials correctly testing his hypothesis within the microworld. Student one's use of the CVS strategy between the pretest and the microworld was consistent; during the pretest he correctly used CVS 100% of the time. Student one managed to correctly interpret his data and drew the correct conclusions for each question asked within the microworld. This was contrary to how he preformed within the inquiry pretest were he failed to draw the correct conclusions from the data provided.

Student two was marked as low inquiry and high content knowledge; he generally performed his experiments incorrectly. While he used CVS on 77.78% of the trials within the microworld during the inquiry pretest he only used CVS 33% of the time. Counting the trials where the student used both CVS and a correct IV resulted in 33.33% of the trials correctly testing his hypothesis within the microworld. Student two performed well on the data interpretation section of the pretest but during the microworld would draw incorrect conclusions or not respond at all. When asked “how is displacement affected by different types of liquids?” he answered “when the object is placed in a different position it floats differently.” Whether this was due to confusion about the question or just not having an answer is unknown from these data.

Student three, moderate inquiry and low content knowledge, generally performed his experiments incorrectly. Student three only used the CVS on 37.50% of his trials while during the pretest he used CVS 100% of the time. Counting the trials where the student used both CVS and a correct IV resulted in 25% of the trials correctly testing his hypothesis within the microworld. Student three answered correctly during the data interpretation section of the pretest but during the microworld would draw incorrect conclusions from his data. For example when asked “how is displacement affected by different types of liquids?” he responded with “it doesnt affect it.[sic]” This is probably a result of the student’s poor performance at correctly conducting experiments; thus his data were confounded on many of his experimental trials because he did not conduct them using CVS (i.e., he only used CVS for 37.50% of his trials).

Student four, who scored low on inquiry and high on content knowledge, performed the worst out of the students when conducting his experiments. Student four used CVS on 50% of her trials and during the inquiry pretest she used CVS 33% of the time. Counting the trials in which the student used both CVS and a correct IV resulted in 12.5% of the trials correctly testing her hypothesis within the microworld. Student four answered the data interpretation section of the pretest incorrectly and when performing experiments within the microworld. Often the student would misinterpret the question being asked or the results of the data. For example “what does the data tell you about the orientation of an object and the amount of liquid displaced?" she responded with "when you drop something more dense into less dense water the water becomes more dense." Here the student is clearly misunderstanding the question and/or the content area.

Student five, who scored moderate on inquiry and moderate on content knowledge, generally performed his experiments incorrectly. Student five used CVS on 54.55% of his trials while during the inquiry pretest he used CVS 67% of the time. Counting the trials where the student used both CVS and a correct IV resulted in 27.27% of the trials correctly testing his hypothesis within the microworld. Student five answered incorrectly on the data interpretation section of the pretest and when performing experiments within the microworld, the student incorrectly interpreted his data. When asked "what does the data tell you about the orientation of an object and the amount of liquid displaced?", he responded, "it tells me that if the density of the block is high then the density of the water must be low in order for it to sink.[sic]" While this is a correct response to why an object will sink or float in a liquid, it's unrelated to the question being asked and was not supported by his trials for the experiment. Thus, he must have used prior content knowledge to answer this question.

Student six was marked on moderate inquiry and high content knowledge. Student six used CVS on 66.67% of his trials while during the pretest he used CVS 67% of the time. Counting the trials where the student used both CVS and a correct IV resulted in 45.45% of the trials correctly testing his hypothesis within the microworld. On data interpretation, student six answered incorrectly during the inquiry pretest, on the microworld experiments he consistently misinterpreted the results. As an example when asked “how is displacement affected by different types of liquids?” he answered “it stays the same as the other.”

Student seven was marked on high inquiry and high content knowledge. Student seven used CVS on 100% of his trials. During the inquiry pretest he used CVS 67% of the time. Counting the trials where the student used both CVS and a selected IV resulted in 50% of the trials correctly testing his hypothesis within the microworld. On data interpretation, student seven answered correctly during the inquiry pretest. While within the microworld, he incorrectly interpreted the data from his experiments. When asked “How is displacement affected by different types of liquids?”, he responded with, “there was more water displacement then oil.[sic]” During this experiment even though the student correctly tested the correct variable, he interpreted an incorrect answer from the data. There was in fact less water displaced due to the oil being less dense than the water during these experiments.

Student eight was marked as high inquiry and high content knowledge. Student eight used CVS on 80.95% of his trials. During the inquiry pretest he used CVS 33% of the time. Counting the trials where the student used both CVS and a correct IV resulted in 28.57% of his trials being performed correctly within the microworld. During the inquiry pretest, student eight correctly interpreted the data provided; in the microworld, he correctly interpreted the data for most of the questions. Student eight was also the only student to correctly identify all three factors in determining if an object sinks or floats in a liquid. While student eight only tested his hypothesis correctly 28.57% of the time his other trials allowed him to correctly answers the questions even if his initial hypothesis was incorrect.

Student nine was marked as high inquiry and high content knowledge. Student nine used CVS on 60.0% of his trials. During the inquiry pretest he used CVS 67% of the time. Counting trials where the student used both CVS and a selected IV resulted in 50% of the trials correctly testing his hypothesis within the microworld. During the inquiry pretest student nine incorrectly interpreted the data provided and within the microworld would occasionally misinterpret his data.

We found that overall students who we marked high inquiry and high content knowledge used CVS more than those in other categories, with two exceptions student one and two. The students also consistently drew incorrect conclusions based off of their experiments. However this is most likely due to them failing to correctly test their hypothesis. Only two students managed to correctly test their hypothesis 50% or more of the time during the experiments. This however didn't prevent them from correctly drawing some correct conclusions as student eight showed. Student eight only correctly tested his hypothesis 28.57% of the time but also sufficiently tested other variables not related to his hypothesis to draw the correct conclusion.

As seen earlier in table 3, students can be grouped into five categories: low inquiry, high knowledge; high inquiry, high knowledge; moderate inquiry, low knowledge; moderate inquiry, moderate knowledge; and moderate inquiry, high knowledge. Since we have looked at each student individually we wanted to see how students in each category performed over all. We also wanted to look for areas were a particular group struggled as a whole. For example did the students within the high content and high inquiry category use CVS consistently? Did a particular category have trouble with data interpretation? This section summarizes trends for students' inquiry actions within the microworlds and their answers to assessment items based on their inquiry and content knowledge groupings.

Students one, two, and four scored low (in fact the lowest of the group tested) on the inquiry pretest, and high on the content knowledge pretest. All students were unable to consistently identify both the dependent and independent variables in the pretest; they sometimes confused the two terms, showing evidence that they did not fully understand the difference between the two terms. None of the students were able to develop a correct hypothesis because they did not structure their hypothesis in the correct if - then format or correctly identify the independent and dependent variables. In terms of the control for variables strategy, students two and four were consistently not aware of how to apply the strategy during the inquiry pretest, both only managing correctly answer 25% of the control for variable strategy questions. Student one managed to correctly answer 75% of the control for variable strategy questions. The question all three students got incorrect was asked directly about the control for variable strategy.

> *"Which of the following is an important thing to remember when testing if one particular variable affects the outcome of a science experiment?"*

All three students responded with:

> *"You should keep some of the variables the same and change the other variables, especially the variable you are testing."*

During the knowledge pretest student one answered one question regarding volume incorrectly; student two answered one question regarding density incorrectly; student four answered one question regarding mass, and one question regarding density incorrectly; their answers reflected that these students were comfortable with the material.

During experimentation, students one and two were generally able to use the control for variables strategy. Student one managed to use a control for variables strategy on 100% of his trials and student two managed to use a control for variables strategy on 77.78% of his trials. Student four managed to use a control for variables strategy on 50% of his trials during experimentation. There is an inconsistency within this group, however, with student skill at conducting experiments to test hypotheses by isolating target variables. Student one, specifically, was able to conduct trials that tested his target variables 83.33% of the time, while the other two students in the group were unable to conduct trials that tested their target variables. Student two only managed to correctly test his target variables 33.33% of the time, and student one only 12.50% of the time. These results were consistent with their results during the inquiry pretest. Student one showed a strong aptitude for conducting experiments that correctly tested the target variable of a hypothesis, while student two and four showed very little skill in this area. While student one was skilled at using the control for variable strategy to test his hypothesis, his weakness at determining the IV showed up during experimentation. An example of this when asked to determine if an objects orientation affected the amount of liquid displaced (assistment 62951), here he selected both the object’s orientation and its mass as variables he would use to test his hypothesis. Student two during the same problem selected both type of liquid and volume of the object; while incorrect it also seems like student two misunderstood the question. Shown by his response “no because if the container is closed the water or liquid will stay in and it wouldn’t matter.” For the rest of the microworlds student two would consistently test variables that were not his target variables and would sometimes fail to test his some of his target variables altogether. Student four also selected the incorrect target variable for assistment 62951: she selected the mass of the object and the volume of the object. Overall, throughout the experiments when asked to select their own target variables all three selected incorrectly save for the last experiment. However, none of them correctly selected all of the correct target variables during the last experiment. During the last experiment only student four selected an incorrect target variable. These students scored different on the posttest; students one and two scored almost perfect, while student four scored lowest with a 22.22 percent.

Students seven, eight, and nine scored high on both the inquiry pre-test and the content knowledge pretests. Student seven scored 50% for independent variable identification, 50% on dependent variable identification, 100% on selecting a hypothesis, 100% on data interpretation, and 75% on the control for variable strategy. Student eight scored 50% for independent variable identification, 50% on dependent variable identification, 50% on selecting a hypothesis, 100% on data interpretation, and 50% on the control for variable strategy. Student nine scored 75% for independent variable identification, 50% on dependent variable identification, 50% on selecting a hypothesis, 0% on data interpretation, and 50% on the control for variable strategy. These students did not perform uniformly or consistently in their inquiry pretest; they were, however, able to identify the independent variable, dependent variable, select a hypothesis, and control for variables strategy at least once. This demonstrates that they are aware of the terms, but may lack a complete understanding of these concepts. On the knowledge pretest, all of these students scored correct answers on all problems except one problem regarding density. This shows that they are knowledgeable with the material, but need more density exploration.

During experimentation, all three students were able to consistently use the control for variables strategy. Student seven managed to use a control for variables strategy on 100% of his trials and student eight managed to use a control for variables strategy on 80.95% of his trials. Student nine managed to use a control for variables strategy on 86.67% of his trials during experimentation.

Student seven was skilled at identifying independent variables, using a control for variables strategy and data interpretation as measured in the pre-test. While experimenting within the microworld, student seven didn’t select an object’s orientation as the target variable when asked if an object’s orientation affects the amount of liquid displaced. Instead he selected the mass of the object. He stated as his hypothesis that the mass will stay the same regardless of the orientation of the object when it is dropped into a liquid. Then when asked if the type of liquid affected displacement, student seven selected type of liquid as his target variable and correctly tested the target variable. Student seven also had a good hypothesis relating a liquids density to how hard it is to displace. However, after conducting the experiment student seven failed to draw the correct conclusion; that water was displaced less than the oil within this experiment. Overall student seven was random in how he conducted his experiments, during one experiment he would test his target variable during another experiment he would completely ignore it only managing to correctly test his target variables 50% of the time. He also performed less well on data interpretation during the microworlds than during the pretest.

Student eight, did very well during experimentation at selecting and testing his target variables. He correctly tested his target variable in every microworld except for the first one, managing to use the control for variable strategy on 80.95% of his trials. Student eight also drew the correct conclusion for all of the microworlds, consistent with his results during the inquiry pretest. Even though student eight only managed to test his target variable 28.57% of the time, this is mainly because he also spent time testing variables that he did not select as a target variable. For example when asked what variables affect if an object will sink or float he selected the mass of the object, but ended up testing every variable and as a result was the only student to correctly select all three of the variables responsible.

During experimentation Student nine did well on selecting and testing his target variables. He selected only orientation of object and type of liquid when asked how each of these affected the displacement of a liquid; this was unsurprising since student nine also had the highest score on the independent variable section of the inquiry pretest. However he only managed to test his target variables on 53.33% of the trials. He also managed to use CVS on 86.67% of his trials an improvement overall performing better than he did during the inquiry pretest. Within the microworld student nine continue to struggle to correctly interpret hisdata. Many of his conclusions are vague and lack detail. When asked *"How is displacement affected by different types of liquids?"* He responded with *"sometimes the objects go into the liquid deeper or not so deep."*

As a group, these students were generally able to conduct proper experiments using with the control for variables strategy, and all students managed to use CVS more than 80% of the time. For the most part, these students had the inquiry skills and knowledge to use their collected information to make some sort of conclusion. However, at times they would not be able to connect their experimentation with the larger content concept under investigation for each question. Student nine for example when asked to test if an object's orientation had an effect on the amount of liquid displaced responded *"no because the amount of liquid is the same no matter wat[sic]"*, and proceeded run a number of trials; only one of which tested if an object's orientation had an effect on the amount of liquid displaced.

Student three scored moderately on the inquiry test managing to identify 50% of the independent and dependent variables, 50% of selecting a hypothesis, 100% of data interpretation, and 75% on the control for variables strategy categories. While student three could correctly identify experiment setups that used the control for variables strategy when asked directly:

> *"Which of the following is an important thing to remember when testing if one particular variable affects the outcome of a science experiment?"*

He responded with *"You should keep some of the variables the same and change the other variables, especially the variable you are testing."* Demonstrating that while he has a general idea of how to conduct an experiment, that is, he must change the variable he is testing, he doesn't understand that other variables may have an effect on the outcome if he does not control them. Student three also scored lowest on the content knowledge test correctly answering questions about volume 33% of the time, mass 100% of the time, and failing to correctly answer the question on density. He was not able to answer the questions that used content terminology, only the ones that described the situation. This shows that student three is not familiar with the terminology, but may have demonstrated some partial understanding of the concepts. On the inquiry pretest, student three was not consistent at correctly identifying independent and dependent variables. This can also be seen in his response when asked *"based on the data from* *the class investigation, what could the students do to make their tire swing move back and forth faster?";* he was able to identify both the independent and dependent variables in his explanation, but could not explain how the IV was responsible for causing the change in the DV. This suggests that student three may have trouble with interpreting data since he claimed to have based his answer on his experience with swings rather than the data provided.

During experimentation, student three did not consistently use a control for variables strategy, only managing to use it on 37.50% of his trials, This is in contrast to his results during the inquiry pretest in which he managed to correctly select experiment setups that used the control for variables strategy. Combined with the trials in which he changed a target variable, which he managed to do 87.50% of the time, this reflects his results from the inquiry pretest. He understands that he needs to change his target variable but not that other variables may have an effect on the results if they are modified simultaneously. As a result, he would often draw incorrect conclusions from the data. While the student did well during the inquiry pretest on data interpretation while in the microworld, working with his own data sets constructed from faulty experimental trials, he didn't perform nearly as well. For example when asked *"how is displacement affected by different types of liquids?"* he responded with *"it doesn't affect it."* This is probably a result of the student's poor performance at correctly conducting experiments; since the only trial he conducted in which he changed the type of liquid he also changed the object's mass, volume, and orientation. Student three scored moderately on the posttest in comparison to the other scores.

Student five scored moderately well on both pretests. For the inquiry pretest, student five's answers were slightly inconsistent. He managed to correctly identify 50% of the independent and dependent variables, 100% of the selecting a hypothesis, 0% on data interpretation and 75% on the control for variables strategy. His answers demonstrated a moderate understanding of independent and dependent variables, and a good understanding of hypotheses and the control for variables strategy. Similarly, his answers on the knowledge pretest were inconsistent. For example during the pretest about volume (assistment 62956), he correctly answered when asked *"Which cereal box can hold the most cereal?"* but when asked immediately after *"Which cereal box has the greatest volume?"* he changed his answer resulting in it being incorrect. He demonstrated that he had a moderate understanding of the topics, but showed misconceptions between volume and mass.

During experimentation, student five demonstrated a basic grasp of testing a hypothesis, managing to correctly test a target variable from the hypothesis 27.27% of the time. He also demonstrated moderate use of the control for variables strategy by only changing a single variable on 63.64% of the trials. Student five performed poorly on the data interpretation section of the pretest and when performing experiments within the microworld, he incorrectly interpreted the data. When asked *"what does the data tell you about the orientation of an object and the amount of liquid displaced?"* he responded *"it tells me that if the density of the block is high then the density of the water must be low in order for it to sink."* While this is a correct response to why an object will sink or float in a liquid, it's unrelated to the question being asked and was not supported by his trials for the experiment, where he only tested an object's orientation once but also changed the objects mass during the same trial. His hypothesis showed a reliance on prior knowledge instead of critical thinking, often only stating whether the initial question asked was correct or not. For example when asked ,*"Do you think the type of liquid affects displacement?"* he responded with *"no I don't think it will."* Student five scored perfectly on the posttest.

Student six scored moderately overall on the inquiry pretest; managing to receive 25% on the independent variable items, 50% on the dependent variable items, 50% on selecting a hypothesis, 0% on data interpretation, and 75% on the control for variables strategy items. During the inquiry pretest, this student was only able to correctly identify a single independent and two dependent variables. He was able, however, to score correctly on the questions regarding the control for variables strategy. He demonstrated a clear understanding of the control for variables strategy when responding to *"Which of the following is an important thing to remember when testing if one particular variable affects the outcome of a science experiment?"* He responded with *"You should change only the variable you are testing and keep all other variables the same."* On the knowledge pretest, student six demonstrated a good understanding of the topics covered, scoring 67% on volume, 100% on mass and 67% on density.

During the experimentation, he demonstrated a strong understanding of testing a hypothesis by testing a target variable on 75.76% of the trials. He also made good use of the control for variables strategy by using it 66.67% of the trials. While he managed to correctly test his target variables 45.45% of the time, he still often misinterpreted his data. For example when asked *"what does the data tell you about the orientation of an object and the amount of liquid displaced?"*, he responded with, *"the orientation of the object has an effect on the amount of* *liquid displaced."* He answer was as stated, despite having conducted two trials that correctly tested an object's orientation on the displacement of liquid.

Suggestions for Further Data Collection

There are three major suggestions for further microworld revisions that reflect the data collected from this pilot study. It is evident in the open response questions that several of the prompts need to be revised to reflect more of what the student is being asked to do. Specifically, the open response questions need to be more explicit. This became evident when answers were coded by hand; for example the students had difficulty with open ended questions like "what can you say about the relationship between the types of liquid and its mass (given the same volume)?" Revising the open response prompts will also possibly lessen the students from misinterpreting the question at hand. Furthermore, many of the students found it difficult to use the correct terminology in their explanations. Therefore, it may be helpful to have a word bank with definitions that pop up when scrolled over to aid students in creating more appropriate responses. These proposals will help give students more direction to help them further explain their answers and to further understand the questions asked of them.

The next major suggestion is to ensure that the logging infrastructure is correctly logged to enable further analysis. Specifically, in the pilot test, students completed the microworlds and sink or float post question, and then repeated the initial pre – tests. Because this section of the post –test was a repeat of both pretests, and the numbers corresponding to the sections were not changed, the student responses to the posttest were not logged, thus, our data analysis was limited to a description of the pre-tests, students' inquiry processes logged within the microworld, and their open responses about the inquiry tasks conducted in the microworld. Having students' post-test performance would have provided a fuller picture of students' learning outcomes.

Finally, it is recommended that the technological infrastructure automatically ensure that the students are not able to continue without trial data. The data analysis shows that one student continuously answered experiment follow up questions without conducting experiments. For this reason, his responses lacked evidentiary support, and were often incorrect. The Assistments infrastructure could provide a prompt if the student tries to continue without conducting an experiment, and not allow the student to proceed until the s/he conducts at least one trial. This will ensure that the students are interacting with the microworlds to test their hypotheses within the microworld.

Conclusions

As previously stated, students need to understand science more deeply, and possess well-honed learning strategies that will allow them to apply their science knowledge in more flexible ways; these are referred to as scientific process skills by national reform documents (NSES, 1989). However, assessing scientific inquiry skills is difficult (Fadel, Honey, & Pasnick, 2007) because hands on, i.e., performance assessments, are more authentic (Baxter and Shavelson 1994; Ruiz-Primo & Shavelson, 1996), but are seldom used in schools due to high costs associated with this. Secondly it is crucial that these skills be assessed in the context in which they are developed (Mislevy et al., 2002).

Teaching and tutoring students on science process skills is an effective way for students acquire both science process skills and transfer these to learn new science content (Gobert et al, 2007; Gobert et al, 2009). The Science Assistments project is working towards developing performance assessments that can be effectively used to assess students' inquiry skills within specific content areas. These microworld-based assessments provide fine-grained performance data of students' science process skills so that tutoring can be honed to students' individual needs as they learn within a rich scientific content domain.

This study contributes to the development of performance assessments for inquiry skills in science in the area of density. The data are important in that they provide a basis upon which to make changes to items, pedagogy, and design interface before the density microworld is implemented into the Science Assistment partner schools. On a broader scale, these assessments and their data are important in terms of what they can tell us about science learning and how it can be facilitated in support of national reform efforts (NSES, 1989).

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Appendix 1: Original Microworld Design

Appendix 1: Original Microworld Design

Microworld Revisions

Mass, Volume, and Density

"Differentiate mass and volume. Define density."

– MA Curricular Framework Learning Strand

Overview

Pretest: What does the student know about mass, volume, and density? Identify basic misconceptions.

Test: Explore each concept individually, and then incorporate them together using the concepts of displacement and floating

Post Test: What do they still hold for misconceptions, or not fully understand about mass, volume, and/or density. Re-take the pretest with different numbers to see any direct conceptual changes, then extend learning in the Microworld to a new problem.

Common Misconceptions for topic: Confusing mass, volume, and their relation to displacement; relating the concepts of mass, volume, and density to type of material in question.

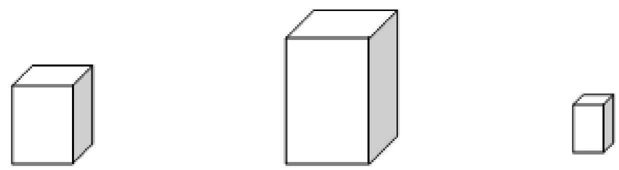
This is a description of the Microworld design. Each following page has a test for the Microworld, in the order in which a student will take the test. There is a box around the image of what the student will see, below is an explanation of how the student will directly interact with the test, then the reasoning behind the activity.

Appendix 1: Original Microworld Design

Pretest Design

Appendix 1: Original Microworld Design

Pretest: One



A: Standard Size Box   B: Family Size Box   C: Individual Size Box

Which cereal box can hold the most cereal?

○ A   ○ B   ○ C

Which cereal box has the greatest volume?

○ A   ○ B   ○ C

Next Question →

Explanation: Students will be given the images above, and fill in the bubble for the correct answer.

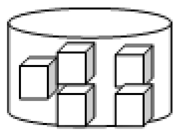
Reasoning: Based on student response to this question, a misconception of the idea of volume will be identified. This will assess their basic understanding of the concept of volume.

Comments:

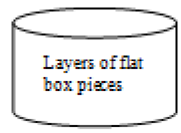
Appendix 1: Original Microworld Design

Pretest: Two

Recycle bin A is filled up to the top with whole empty boxes of cereal. Recycle bin B is filled to the top with the same kind of boxes ripped to pieces. Recycle bin A and B are the same size.



A: Filled with Whole Cereal Boxes



B: Filled with Pieces of Cereal Boxes

Is one recycle bin heavier to pick up?

○ A is heavier ○ B is heavier ○ They are the same

Does one bin have a higher ***mass***?

○ A has a higher mass ○ B has a higher mass ○ They are the same

Can you pack more whole boxes in recycle bin A or more shredded boxes in recycle bin B?

○ More in A ○ More in B ○ They are the same

Which bin has a higher ***density*** of cereal boxes?

○ A has a higher density ○ B has a higher density ○ They are the same

Next Question →

Explanation: Students will be given the questions and images above. They will fill in the bubbles to answer.

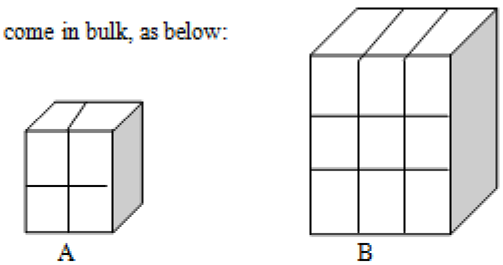
Reasoning: Here, volume is constant; density is introduced as "packing" density. This allows us to evaluate student understanding of density from the perspective/concept of "packing" density. The follow up questions are aimed at determining if they recognize mass as an amount of material. The second set of questions is to find their level/depth of understanding density (terminology-wise).

Comments:

Appendix 1: Original Microworld Design

Pretest: Three

Cereal boxes often come in bulk, as below:



Stack A has 4 boxes of cereal; stack B has 9 boxes of the same cereal.

Which stack of cereal has a higher density?

○ A ○ B ○ They have the same density

Next Question →

Explanation: Students will be given the images above, and fill in the bubble for the correct answer.

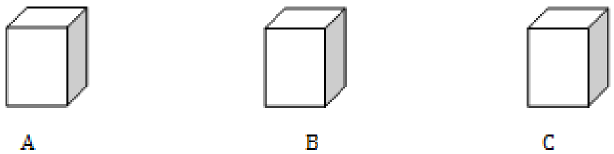
Reasoning: Based on student response to this question, a misconception of the idea of volume will be identified. This will assess their basic understanding of the concept of volume.

Comments:

Appendix 1: Original Microworld Design

Pretest: Four

Mystery Cereals: Same Volume



Which cereal box has the highest density?

○ A ○ B ○ C ○ Not enough information

What additional information would you need to determine which mystery cereal box has the highest density?

Continue to Microworld →

Explanation: Students will be shown the mystery boxes above. They will fill in the bubble for the correct answer before continuing to start the Microworld activities.

Reasoning: This will demonstrate of the students realize they need to know the material (hence the density) that will allow them to answer the question. This can be repeated for mass, as necessary.

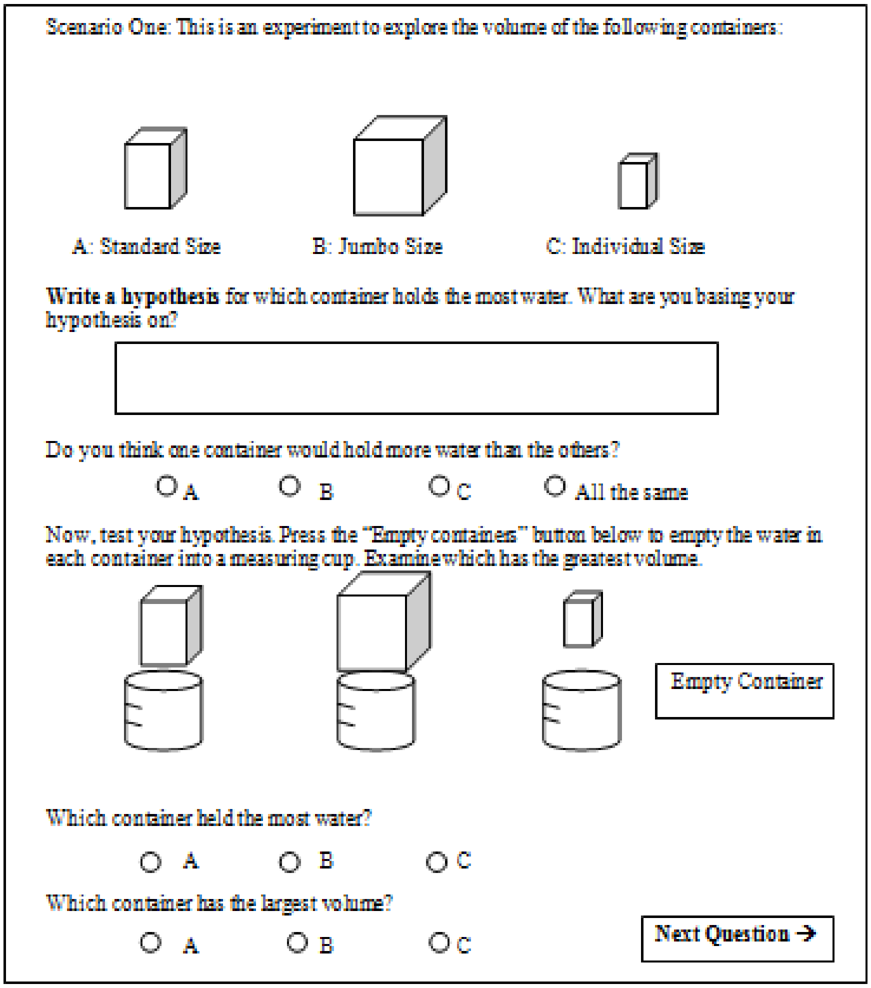
*Note that all of these designs should include detail for the cereal boxes; the more exciting the colors and designs, the more we will be able to draw the kids in.

Comments:

Appendix 1: Original Microworld Design

Microworld Design

Appendix 1: Original Microworld Design



Explanation: Students will be given the above scenario. They will be asked to guess, hypothesize, and then press a button to interact with the Microworld to explore the concept of volume.

Reasoning: This Microworld will give students a chance to demonstrate what they understand about the concept of volume, as well as experiment to solidify basic understanding. By filling simple prisms with water and emptying them into beakers, the concept of volume in parallel with size will be apparent.

Comments:

Appendix 1: Original Microworld Design

Microworld: Two – Volume Exploration, Continued

Scenario Two: You are going to experiment with containers of different shapes.

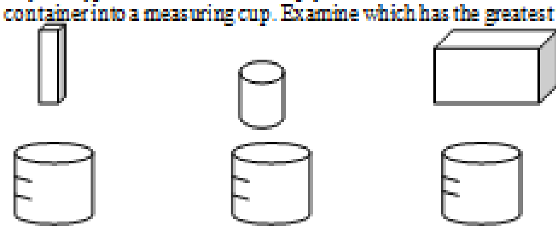
A B C

Write a hypothesis for which container has the greater volume. What are you basing your hypothesis on?

Do you think one container has a greater volume than the others?

○ A ○ B ○ C ○ All the same

Now, test your hypothesis. Press the "Empty Containers" button below to empty the water in each container into a measuring cup. Examine which has the greatest volume.



Empty Containers

Which container had the highest volume?

○ A ○ B ○ C

Which container had the lowest volume?

○ A ○ B ○ C

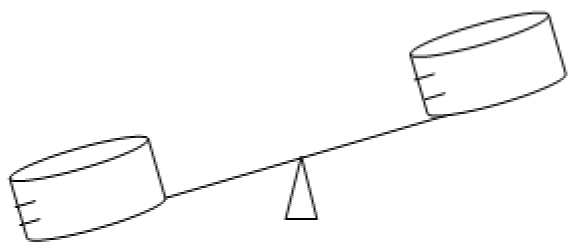
Next Question →

Explanation: **Repeat the experiment above with different shapes and same sizes to show you can have the save volume with different shapes. Same as previous, first different shapes with the same volume, the different shapes and different volumes

Reasoning: This will give students the opportunity to see the impact of shape on volume. First, they will be given a situation where one object is obviously larger, therefore has greater volume. They will then have to experiment with a situation in which the three objects have the same volume, to show that shape does not exactly correlate to volume based on apparent size. This is an essential lesson before going more in depth with the Microworld to explore mass and density. **Comments:**

Below are two containers on a scale. As liquid is added to each container the scale will show the weight of each liquid, and the volume of the liquid. Use the scale to answer the following questions. Hit the "Record data" button to save the current state of the liquids and the balance on the table provided.

Do you think the shape of the container will affect the mass of the liquid inside? Write a hypothesis that explains your reasoning below?



Record Now

Left Container	
Increase Liquid 1 ▲	Decrease Liquid 1 ▼
Small Container	⬇

Right Container	
Increase Liquid 2 ▲	Decrease Liquid 2 ▼
Small Container	⬇

	Left Container			Right Container		
Trial	Container Size	Liquid Type	Mass	Container Size	Liquid Type	Mass

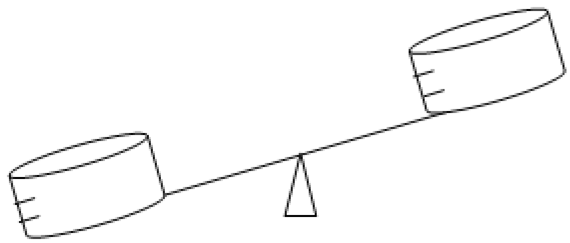
What can you conclude about the relationship between the shape of the container and the mass of the liquid?

What Trials are you basing your conclusion on?

Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6

Below are two containers on a scale. As liquid is added to each container the scale will show the weight of each liquid, and the volume of the liquid. Use the scale to answer the following questions. Hit the "Record data" button to save the current state of the liquids and the balance on the table provided.

Do you think the type of liquid will affect mass? Write a hypothesis that explains your reasoning below?



Record Now

Left Container	
Increase Liquid 1 ▲	Decrease Liquid 1 ▼
Small Container	▼

Right Container	
Increase Liquid 2 ▲	Decrease Liquid 2 ▼
Small Container	▼

	Left Container			Right Container		
Trial	Container Size	Liquid Type	Mass	Container Size	Liquid Type	Mass

At equal masses which liquid has the largest volume? What can you determine about this liquid?

What Trials are you basing your conclusion on?

Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6

Appendix 1: Original Microworld Design

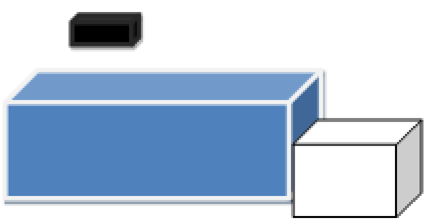
Microworld 2:

Below are two containers. When the object is dropped into the larger container it will push liquid from the larger container into the smaller container, this liquid is said to be displaced.

Does flipping or rotating an object affect the amount of liquid it displaces? Write a hypothesis that explains your reasoning below.

Hypothesis from student.

Conduct an experiment below to test your hypothesis. Use the drop down menus to change the values of each variable, then press the "Run Experiment" button to gather data in the table below. Repeat as necessary.



Mass | Volume

Liquid Type | Orientation of Object | Run Experiment | Reset

Trial	Mass	Volume	Object's Density*	Liquid	Mass of Liquid Displaced	Volume of Liquid Displaced	Density of liquid
1							

What can you conclude about the orientation of an object and the amount of water displaced based on your data?

What Trials are you basing your conclusion on?

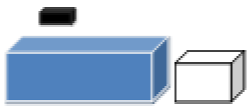
Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6

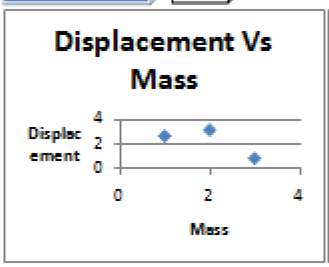
Below are two containers. When the object is dropped into the larger container it will push liquid from the larger container into the smaller container, this liquid is said to be displaced.

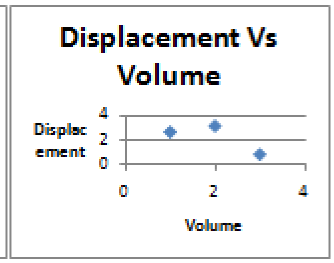
Do you think mass and volume affect the amount of liquid that is displaced? Write a hypothesis that explains your reasoning below.

Hypothesis from student.

Conduct an experiment below to test your hypothesis. Use the drop down menus to change the values of each variable, then press the "Run Experiment" button to gather data in the table below. Repeat as necessary.







Mass ▼ | Volume ▼

Liquid Type ▼ | Orientation of Object ▼ | Run Experiment | Reset

Trial	Mass	Volume	Object's Density*	Liquid	Mass of Liquid Displaced	Volume of Liquid Displaced	Density of liquid
1							

What can you conclude about the relationship between object's mass and volume and the amount of liquid displaced?

What Trials are you basing your conclusion on?

Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6

What do you notice about the density of the object (calculated) and the amount of liquid displaced?

What Trials are you basing your conclusion on?

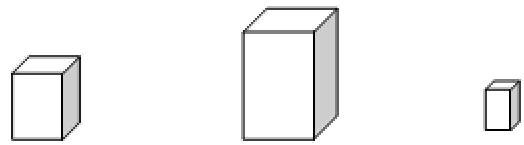
Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6

Appendix 1: Original Microworld Design

Post-Test Design

Appendix 1: Original Microworld Design

Posttest: One



A: Standard Size Box B: Family Size Box C: Individual Size Box

Which cereal box can hold the most cereal?

○ A ○ B ○ C

Which cereal box has the greatest volume?

○ A ○ B ○ C

Next Question →

Explanation: Students will be given the images above, and fill in the bubble for the correct answer.

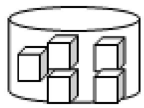
Reasoning: Based on student response to this question, a misconception of the idea of volume will be identified. This will assess their basic understanding of the concept of volume.

Comments:

Appendix 1: Original Microworld Design

Pretest: Two

Recycle bin A is filled up to the top with whole empty boxes of cereal. Recycle bin B is filled to the top with the same kind of boxes ripped to pieces. Recycle bin A and B are the same size.



A: Filled with Whole Cereal Boxes

B: Filled with Pieces of Cereal Boxes

Is one recycle bin heavier to pick up?

○ A is heavier ○ B is heavier ○ They are the same

Does one bin have a higher ***mass***?

○ A has a higher mass ○ B has a higher mass ○ They are the same

Can you pack more whole boxes in recycle bin A or more shredded boxes in recycle bin B?

○ More in A ○ More in B ○ They are the same

Which bin has a higher ***density*** of cereal boxes?

○ A has a higher density ○ B has a higher density ○ They are the same

Next Question →

Explanation: Students will be given the questions and images above. They will fill in the bubbles to answer.

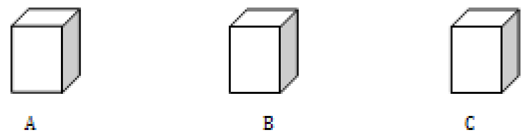
Reasoning: Here, volume is constant, density is introduced as "packing" density. This allows us to evaluate student understanding of density form the perspective/concept of "packing" density. This follow up questions are aimed at determining if they recognize mass as an amount of material. The second set of questions is to find their level/depth of understanding density (terminology-wise).

Comments:

Appendix 1: Original Microworld Design

Posttest: Four

Mystery Cereals: Same Volume



Which cereal box has the highest density?

○ A ○ B ○ C ○ Not enough information

What additional information would you need to determine which mystery cereal box has the highest density?

Continue to Microworld →

Explanation: Students will be shown the mystery boxes above. They will fill in the bubble for the correct answer before continuing to start the Microworld activities.

Reasoning: This will demonstrate of the students realize they need to know the material (hence the density) that will allow them to answer the question. This can be repeated for mass, as necessary.

*Note that all of these designs should include detail for the cereal boxes; the more exciting the colors and designs, the more we will be able to draw the kids in.

Comments:

Appendix 1: Original Microworld Design

Students will be re-given the pre-test. This will determine if their understanding of the concepts and situations provided there have changed with the activities in the Microworld. They will then take the following test to determine if they are able to extend the learning from the Microworld to an activity based off the final experimentation.

In the Microworld activities, you experimented with combinations of liquid and object type to determine their role in whether or not an object sinks or floats. Here, you will be given combinations of objects and liquids, and it is your job to decide whether you believe the object will sink (fully submerged) or float (fully or partially submerged). You will be given the density of each.

Objects: Lead ball - Density 11.5, Maple Wood ball – Density 0.75, Rubber ball – Density 5.0

Liquids: Salt water – Density 1.5, Rubbing alcohol – Density 0.5, Liquid mercury – Density 13.5

Combination: Lead Ball and Salt Water

○ Sink ○ Float

*****POST TEST WILL REPEAT FOR ALL COMBINATIONS*****

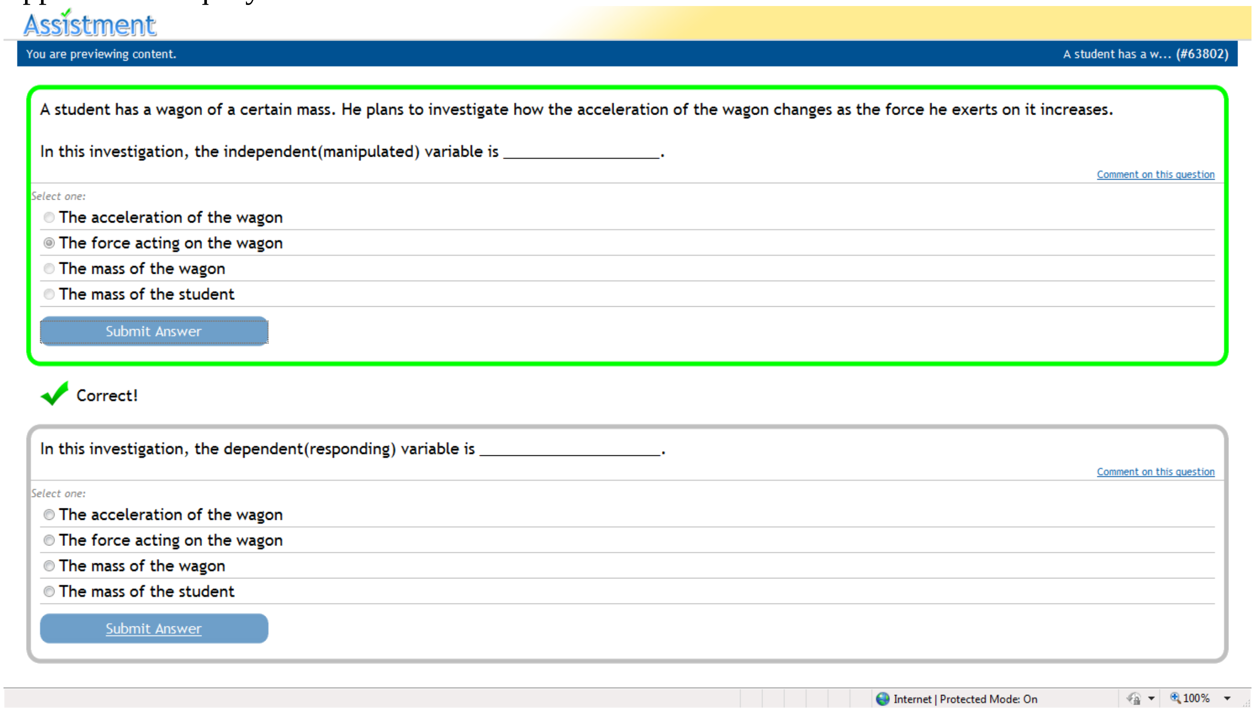
Next Question →

Explanation: Students will be given the above situation. They will fill in the bubble for the combination given. They will cycle through all combination by clicking "Next Question."

Reasoning: This will give students the chance to apply what they found from experimenting with the Microworld to a new situation. Answer to this will demonstrate a student's understanding of the concept that an object will sink if its density is greater than that of the water. Here, students are not allowed to test as they had been doing in the Microworld. They instead have to rely on values for density, which is a new idea introduced only here.

Comments

Appendix 2: Inquiry Pretest


Assistment

You are previewing content. A student has a w... (#63802)

A student has a wagon of a certain mass. He plans to investigate how the acceleration of the wagon changes as the force he exerts on it increases.

In this investigation, the independent(manipulated) variable is _________________.

Comment on this question

Select one:

- The acceleration of the wagon
- The force acting on the wagon
- The mass of the wagon
- The mass of the student

Submit Answer

Correct!

In this investigation, the dependent(responding) variable is ____________________.

Comment on this question

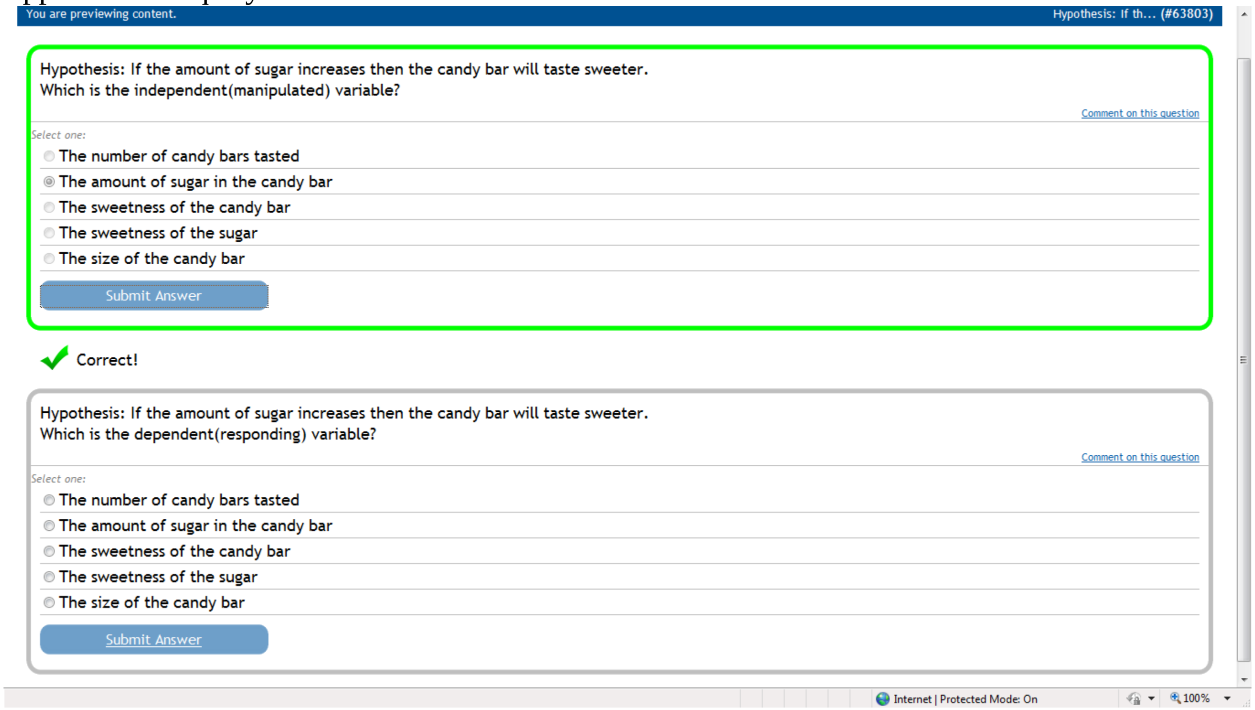
Select one:

- The acceleration of the wagon
- The force acting on the wagon
- The mass of the wagon
- The mass of the student

Submit Answer

Internet | Protected Mode: On 100%

Appendix 3: Inquiry Pretest

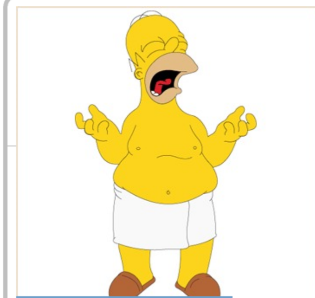


Appendix 4: Inquiry Pretest

Appendix 4A

ASSISTments

You are previewing content. Homer noti... (#63989)



Homer notices that his shower is covered in a strange green slime. His friend Barney tells him that coconut juice will get rid of the green slime. Homer decides to check this out by spraying half of the shower with coconut juice. He sprays the other half of the shower with water. After 3 days of the "treatment" there is no change in the appearance of the green slime on either side of the shower.

a) What was the manipulated(independent) variable?

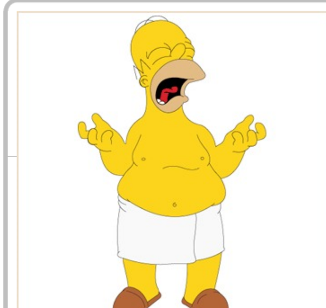
Comment on this question

Select one:

- Barney's idea to use coconut juice
- The amount of slime removed
- The change in the appearance of the shower
- The shower halves
- Whether juice or water is sprayed

Submit Answer

Appendix 4B



Homer notices that his shower is covered in a strange green slime. His friend Barney tells him that coconut juice will get rid of the green slime. Homer decides to check this out by spraying half of the shower with coconut juice. He sprays the other half of the shower with water. After 3 days of the "treatment" there is no change in the appearance of the green slime on either side of the shower.

b) What was the dependent(responding) variable?

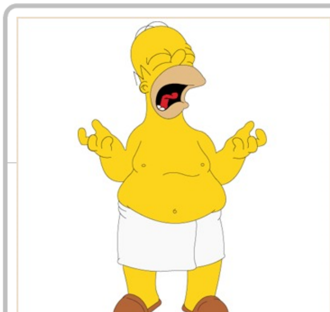
Comment on this question

Select one:

- The amount of slime on the two halves of the shower
- The amount of water or juice on the two halves of the shower
- Whether juice or water is sprayed
- Barney's idea to use coconut juice
- The three days spent spraying the shower

Submit Answer

Appendix 4C



Homer notices that his shower is covered in a strange green slime. His friend Barney tells him that coconut juice will get rid of the green slime. Homer decides to check this out by spraying half of the shower with coconut juice. He sprays the other half of the shower with water. After 3 days of the "treatment" there is no change in the appearance of the green slime on either side of the shower.

c) What would be a valid hypothesis for Homer's experiment?

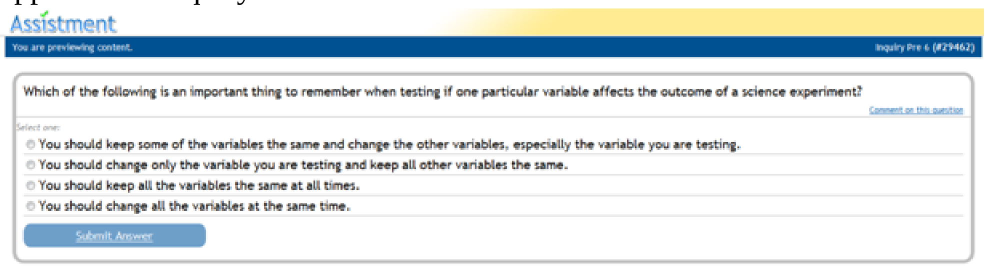
Comment on this question

Select one:

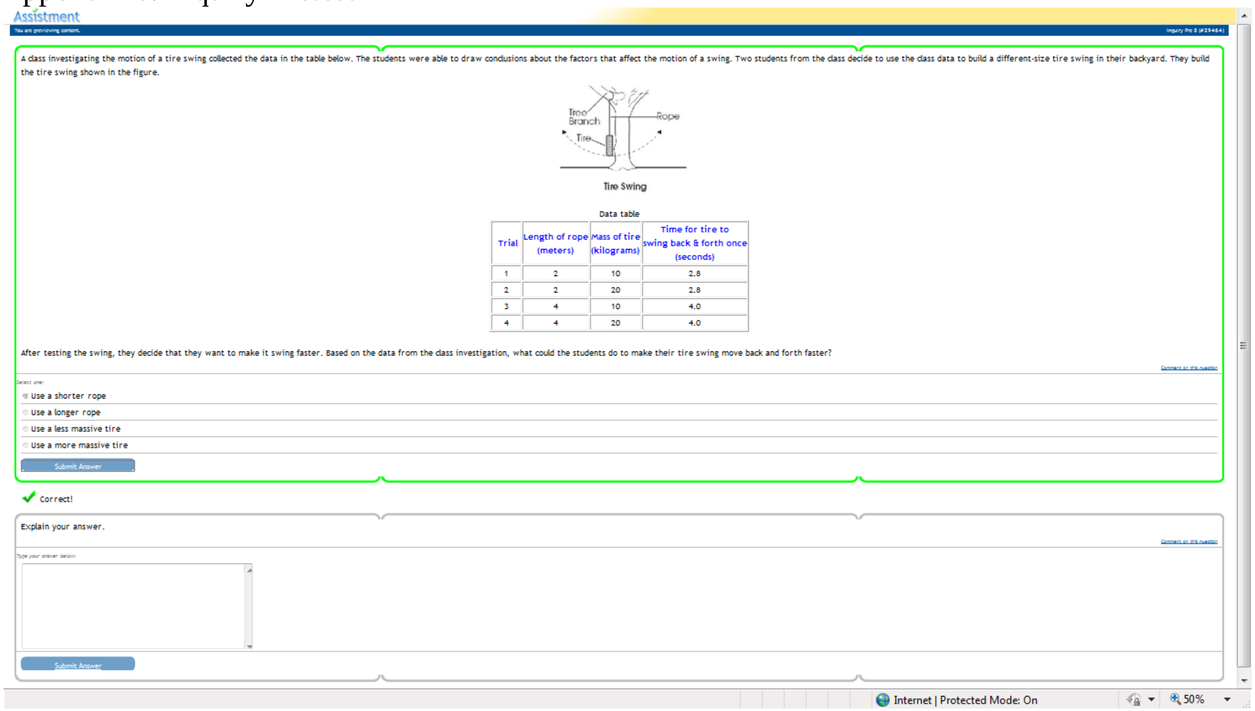
- Coconut juice removes more slime than water.
- Three days is enough time to remove slime.
- Coconut juice tastes better than water.
- Barney believes that coconut juice removes slime, so it must be wrong.
- Barney believes that coconut juice removes slime, so it must be right.

Submit Answer

Appendix 5: Inquiry Pretest



Appendix 6: Inquiry Pretest



Assistment

You are previewing content.

A class investigating the motion of a tire swing collected the data in the table below. The students were able to draw conclusions about the factors that affect the motion of a swing. Two students from the class decide to use the class data to build a different-size tire swing in their backyard. They build the tire swing shown in the figure.

Tire Swing

Data table

Trial	Length of rope (meters)	Mass of tire (kilograms)	Time for tire to swing back & forth once (seconds)
1	2	10	2.8
2	2	20	2.8
3	4	10	4.0
4	4	20	4.0

After testing the swing, they decide that they want to make it swing faster. Based on the data from the class investigation, what could the students do to make their tire swing move back and forth faster?

Comment on this question

Select one:

- Use a shorter rope
- Use a longer rope
- Use a less massive tire
- Use a more massive tire

Submit Answer

Correct!

Explain your answer.

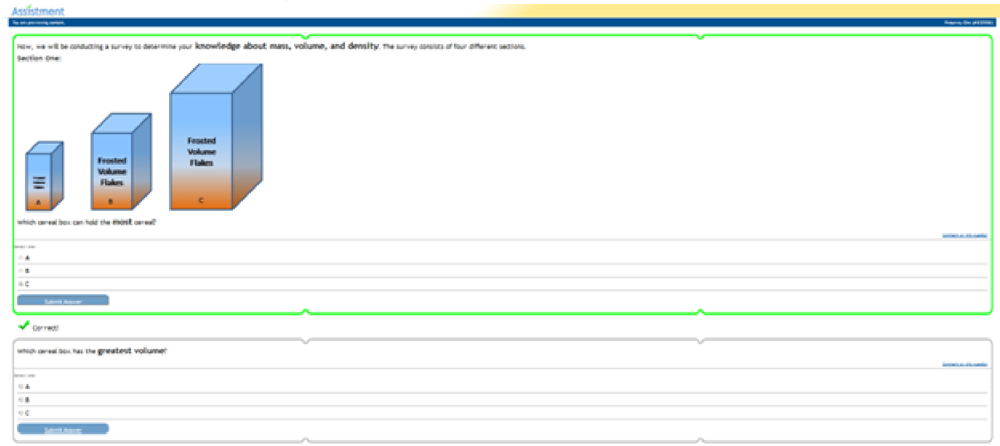
Comment on this question

Type your answer below:

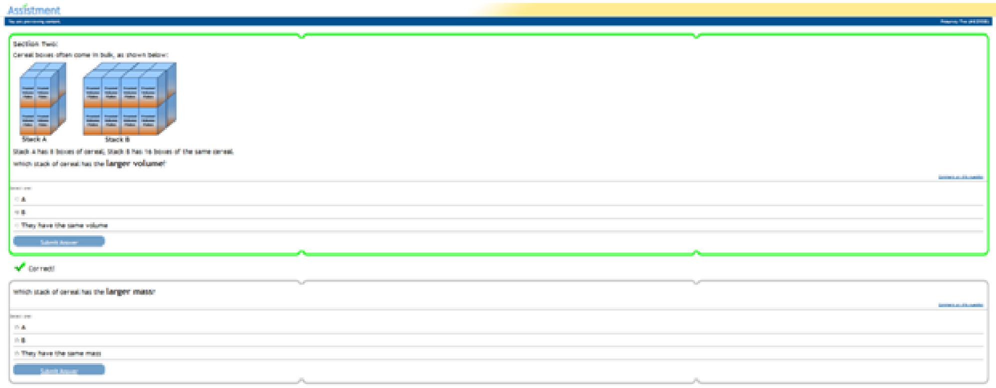
Submit Answer

Internet | Protected Mode: On 50%

Appendix 7: Knowledge Pretest



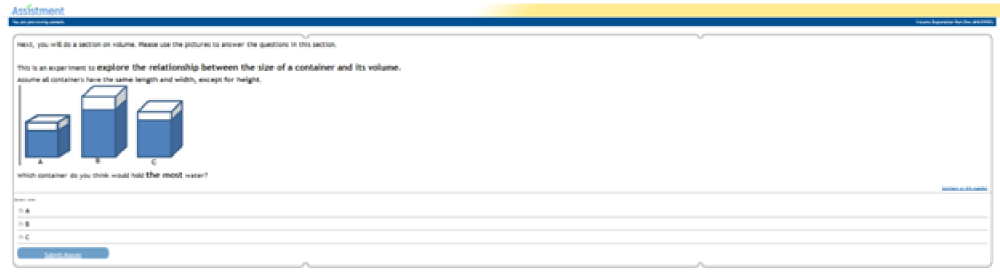
Appendix 8: Knowledge Pretest



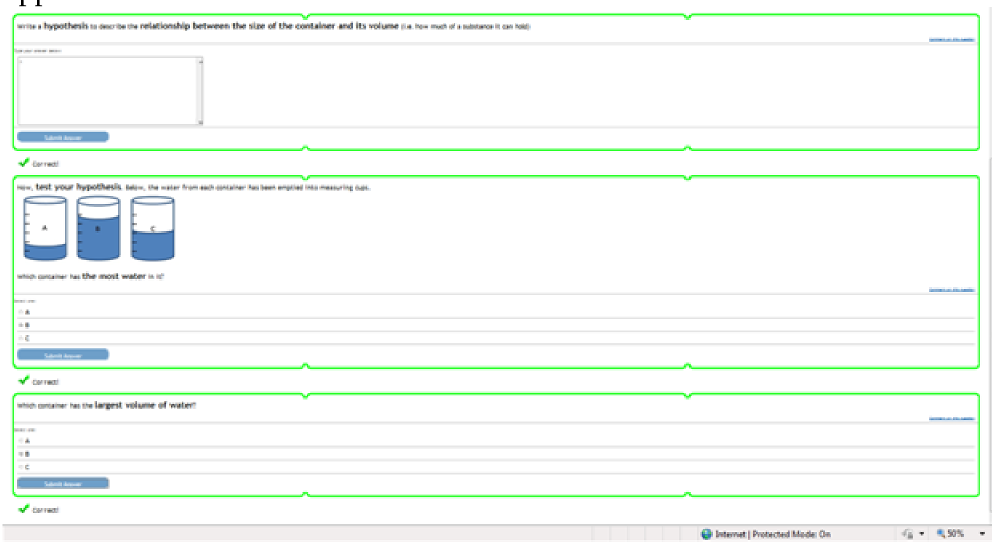
Appendix 9: Knowledge Pretest

Appendix 10:

Appendix 10A: Microworld 1



Appendix 10B: Microworld 1



Appendix 11: Microworld 2

You are previewing content. Density Balance Microworld One (#64326)

This portion deals with the differences in liquids and the effects of the containers that hold them. It has two sections.

Section One:
Now we will be determining if the container size has an effect on the mass of the liquid.

Do you think the shape of a container affects the mass of the liquid it contains?

Comment on this question

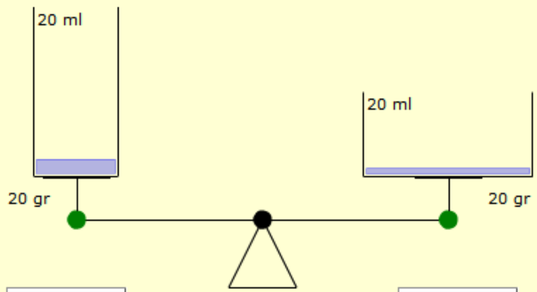
Select one:

- Yes
- No

Submit Answer

Appendix 11: Microworld 2

Below are two containers on a scale and a table for collecting data. Add or subtract liquid from each container until you think the two sides are balanced. Then click the "Record" button, this will record data from the scale onto the table. Use your data to answer the following questions.



Add Water | Sub Water | Record | Add Water | Sub Water

Left Substance: Water
Left Container: Narrow
Right Substance: Water
Right Container: Wide

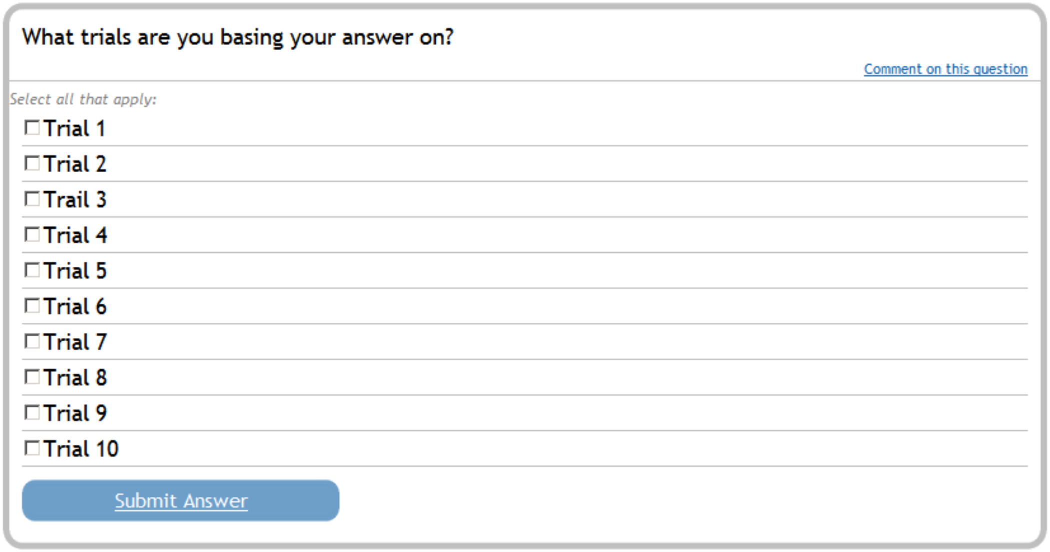
Trial Number ------	Left Container Shape	Left Liquid Type	Left Liquid Mass	Left Liquid Volume	Right Container Shape	Right Liquid Type	Right Liquid Mass	Right Liquid Volume
1	Narrow	Water	20	20	Wide	Water	20	20

What can you conclude about the relationship between the shape of the container and the mass of the liquid?

Comment on this question

Type your answer below:

Submit Answer



What trials are you basing your answer on?

Comment on this question

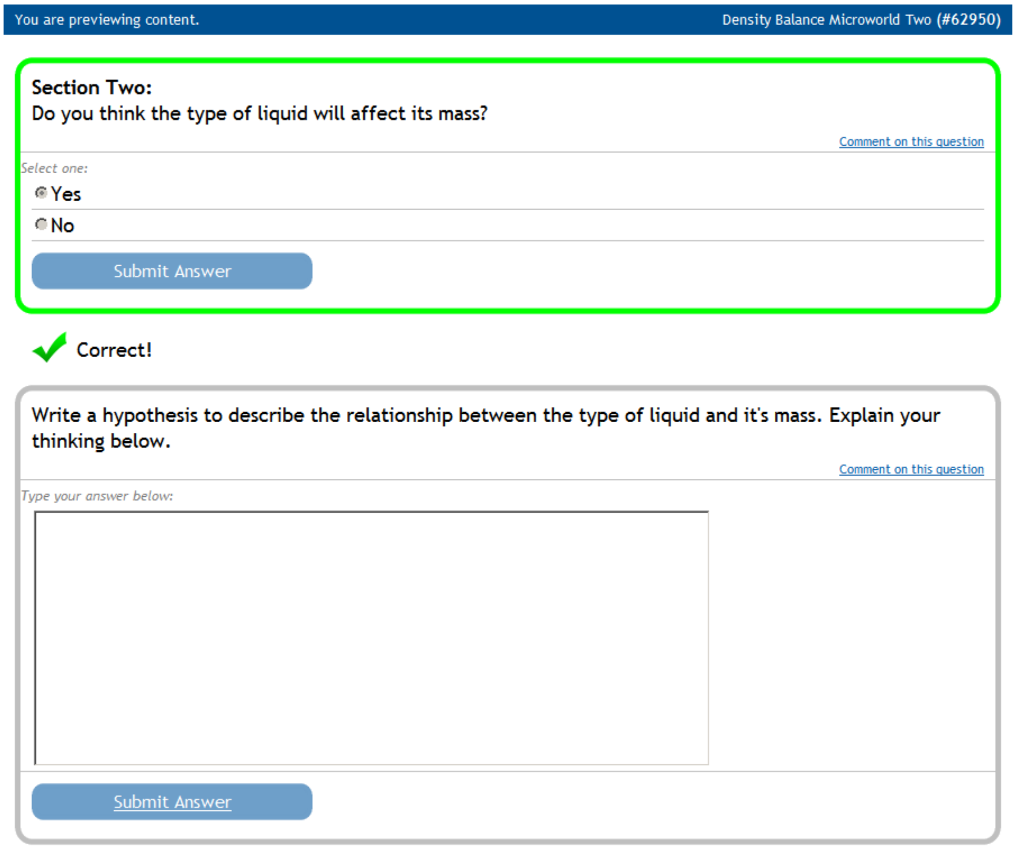
Select all that apply:

- ☐ Trial 1
- ☐ Trial 2
- ☐ Trail 3
- ☐ Trial 4
- ☐ Trial 5
- ☐ Trial 6
- ☐ Trial 7
- ☐ Trial 8
- ☐ Trial 9
- ☐ Trial 10

Submit Answer

Appendix 12: Microworld 2

Appendix 12A



You are previewing content. Density Balance Microworld Two (#62950)

Section Two:
Do you think the type of liquid will affect its mass?

Comment on this question

Select one:

- Yes
- No

Submit Answer

Correct!

Write a hypothesis to describe the relationship between the type of liquid and it's mass. Explain your thinking below.

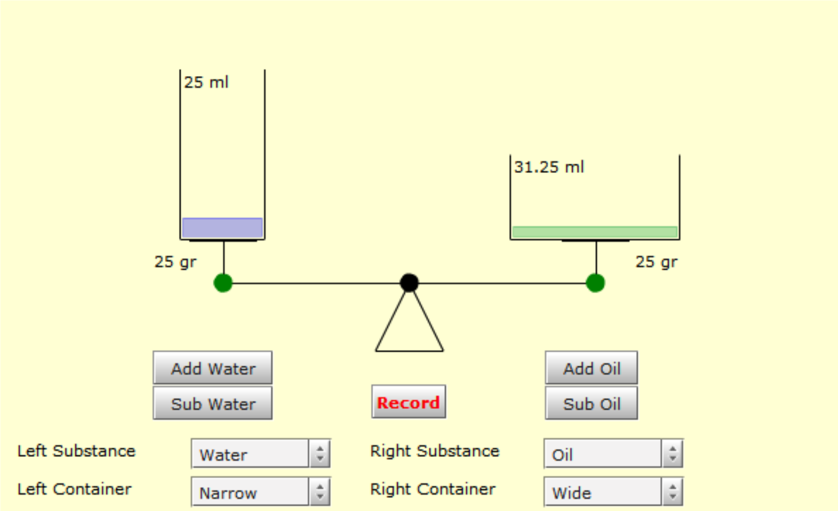
Comment on this question

Type your answer below:

Submit Answer

Appendix 12B

Below are two containers on a scale and a table for collecting data. Change the type of liquid in one of the containers and then add or subtract liquid from each container until you think the two sides are balanced. Then click the "Record" button, this will record data from the scale onto the table. Use your data to answer the following questions.



Trial Number ------	Left Container Shape	Left Liquid Type	Left Liquid Mass	Left Liquid Volume	Right Container Shape	Right Liquid Type	Right Liquid Mass	Right Liquid Volume
1	Narrow	Water	25	25	Wide	Oil	25	31.25

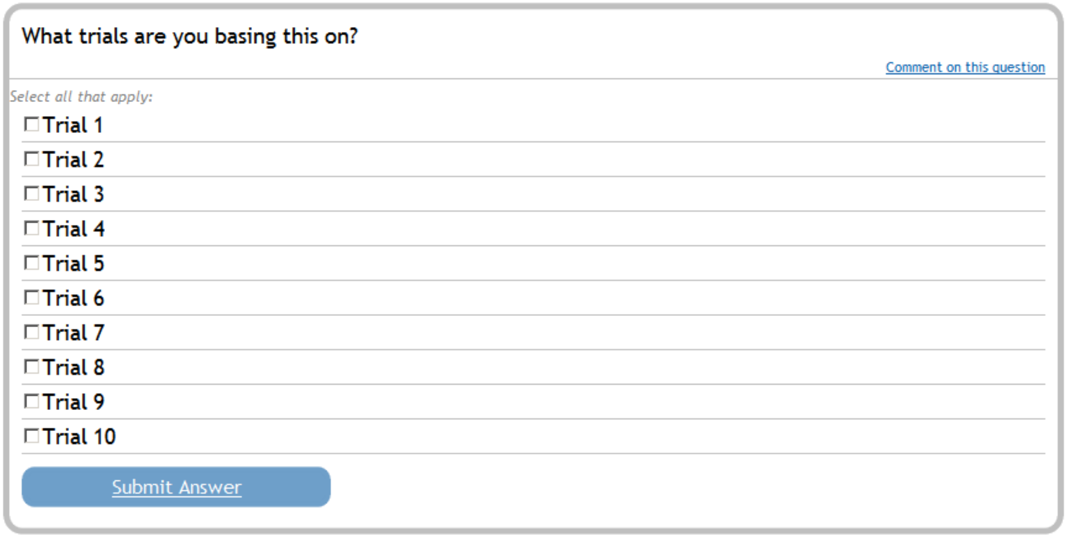
When both containers are of equal mass, which liquid has the largest volume?

Comment on this question

Select one:

- Water
- Oil
- They are the same

Submit Answer



What trials are you basing this on?

Comment on this question

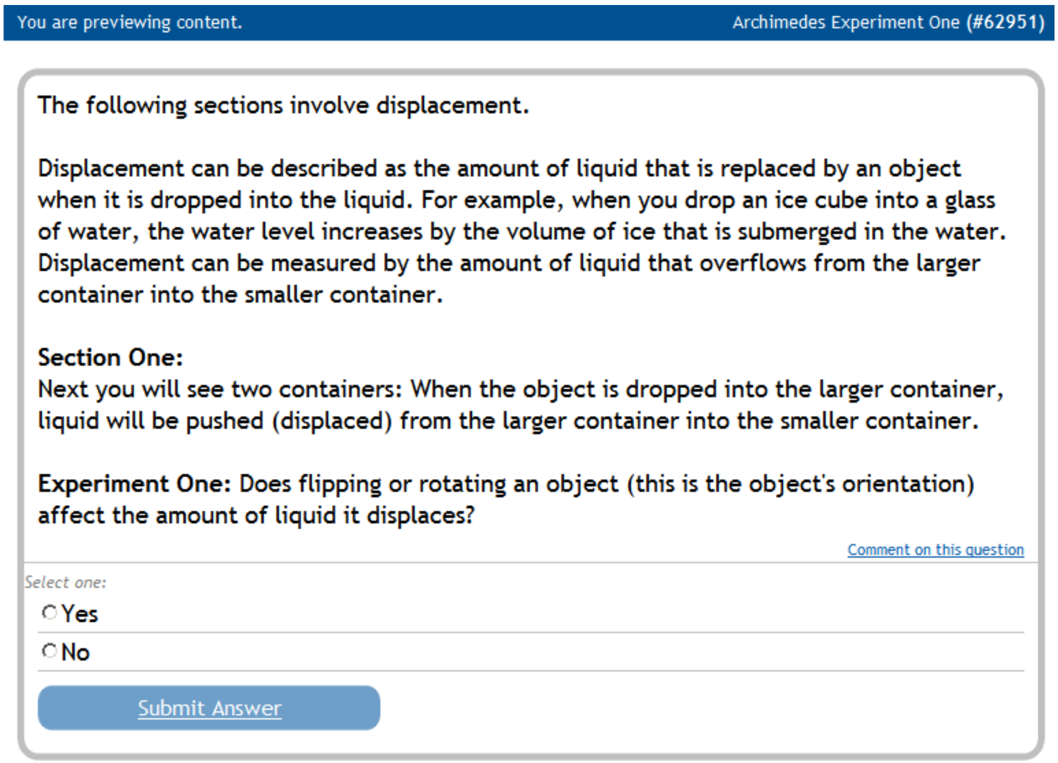
Select all that apply:

- ☐ Trial 1
- ☐ Trial 2
- ☐ Trial 3
- ☐ Trial 4
- ☐ Trial 5
- ☐ Trial 6
- ☐ Trial 7
- ☐ Trial 8
- ☐ Trial 9
- ☐ Trial 10

Submit Answer

Appendix 13: Microworld 3

Appendix 13A



Write your hypothesis below.

Comment on this question

Type your answer below:

Submit Answer

Which variables will you use to test your hypothesis?

Comment on this question

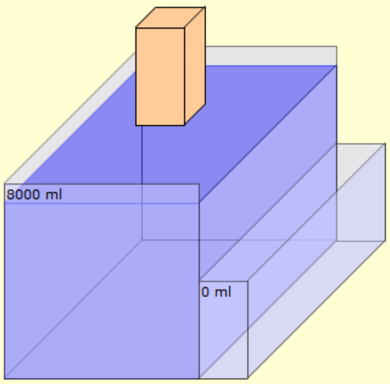
Select all that apply:

- ☐ Mass of object
- ☐ Volume of object
- ☐ Type of liquid
- ☐ Orientation of object

Submit Answer

Appendix 13B

Now use the microworld to test your hypothesis.



Drop Object | Reset

Liquid: Water

Object Mass: 50gr

Volume: 100ml

Orientation: Vertical

	Independent Variables				Dependent Variables			Other Data
Trial Number	Liquid Type	Object Mass	Object Volume	Object Orientation	Object Density	Mass Displaced	Volume Displaced	Liquid Density

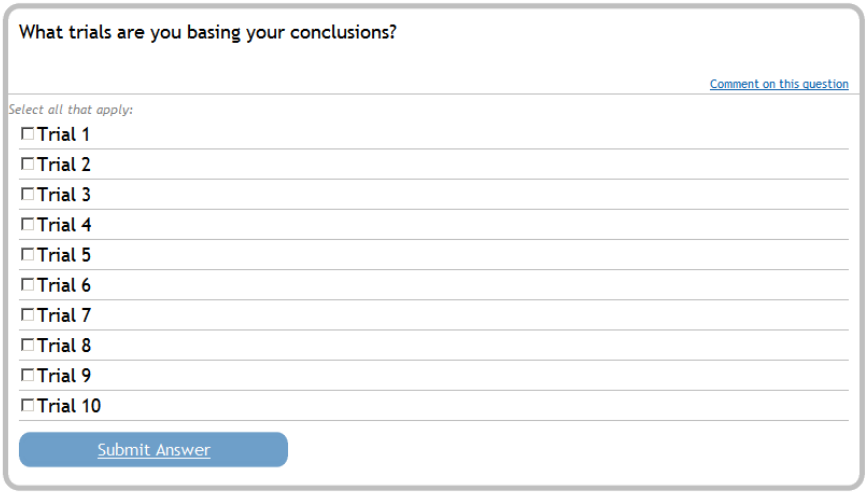
Looking at the trial table, what does the data tell you about the realtionship betwen the orientation of an object and the amount of liquid displaced?

Comment on this question

Type your answer below:

Submit Answer

Appendix 13C



What trials are you basing your conclusions?

Comment on this question

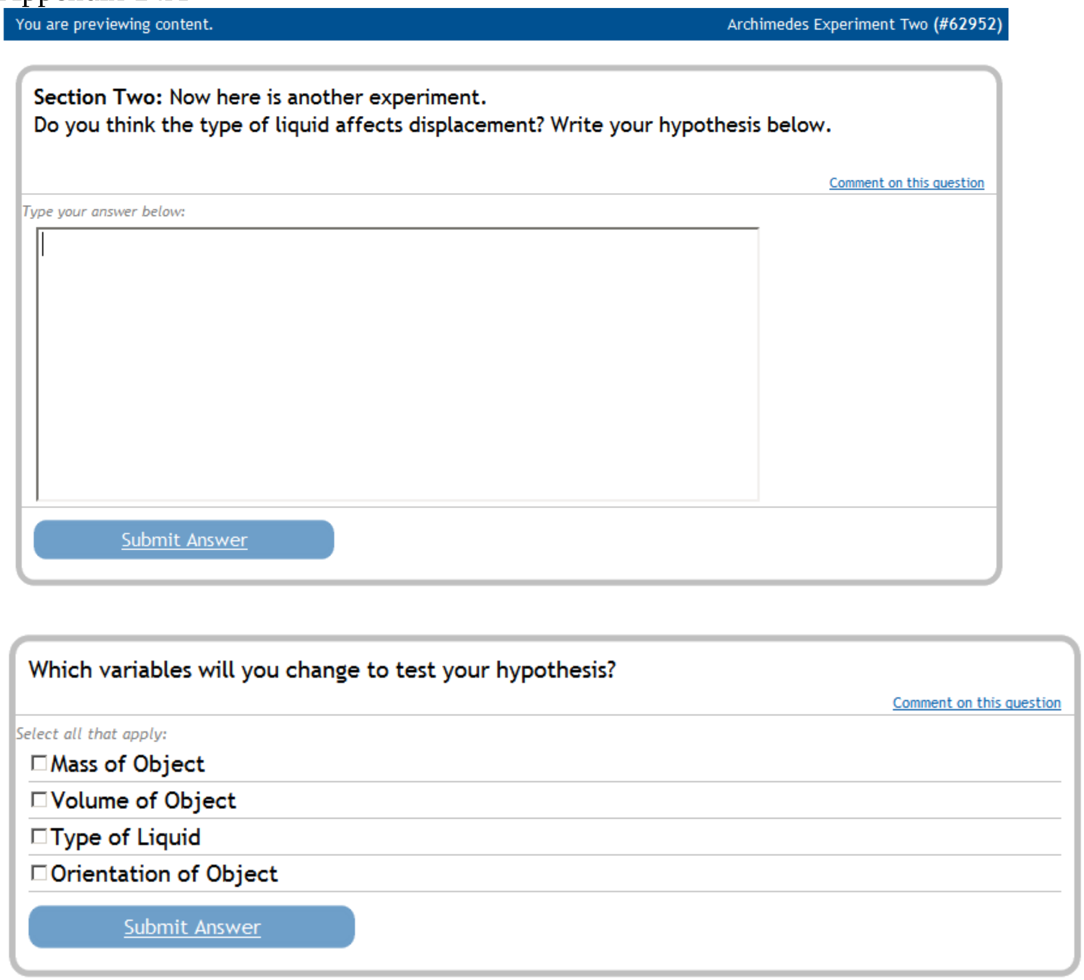
Select all that apply:

- ☐ Trial 1
- ☐ Trial 2
- ☐ Trial 3
- ☐ Trial 4
- ☐ Trial 5
- ☐ Trial 6
- ☐ Trial 7
- ☐ Trial 8
- ☐ Trial 9
- ☐ Trial 10

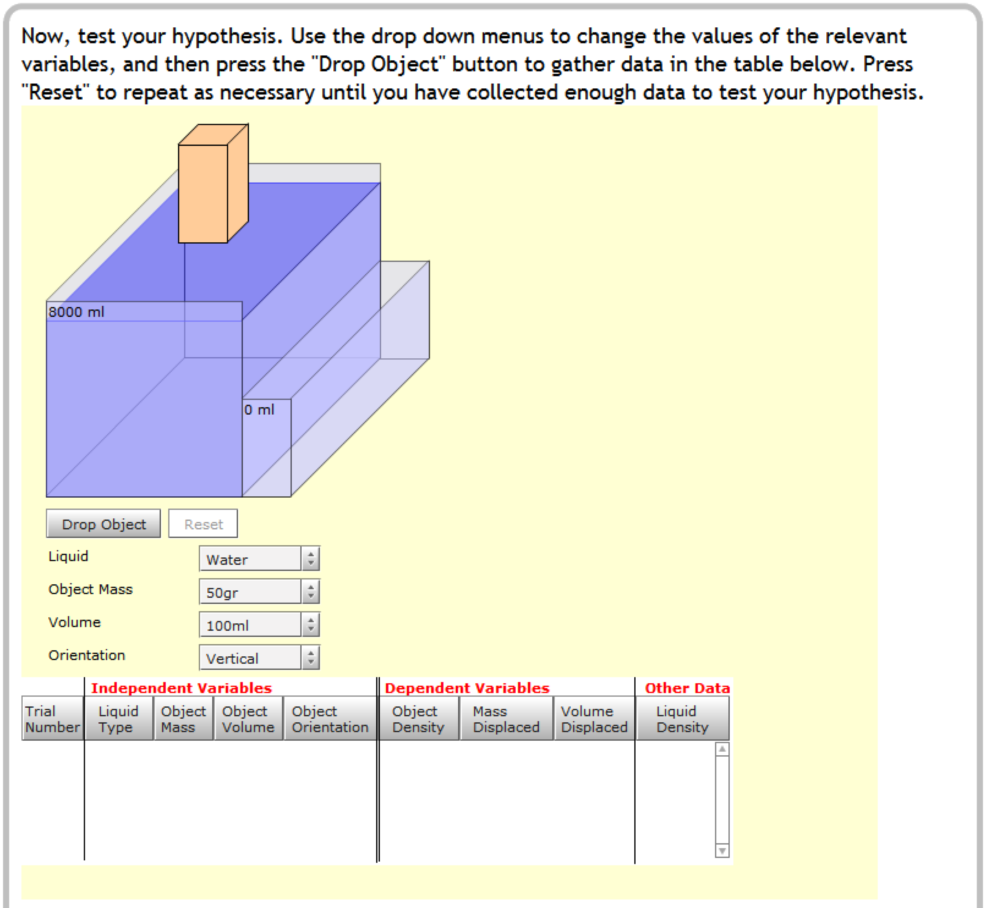
Submit Answer

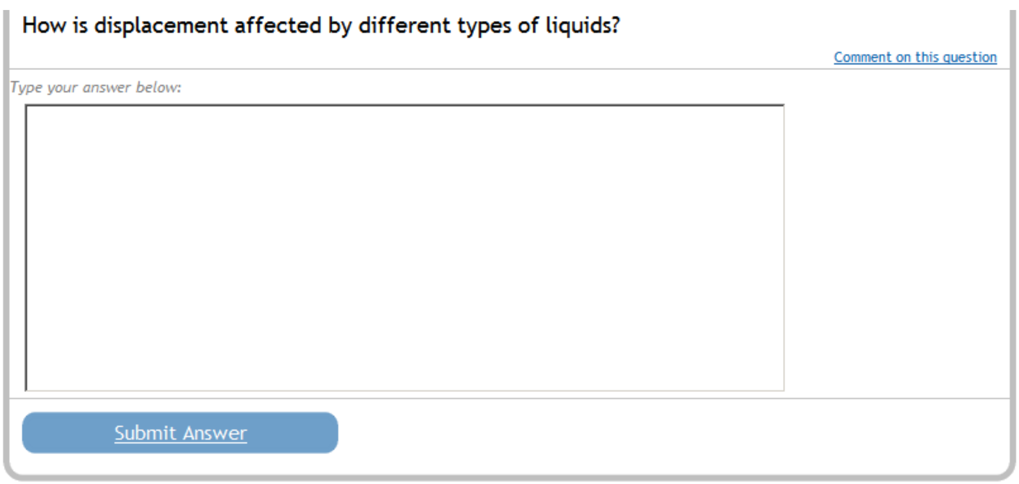
Appendix 14: Microworld 3

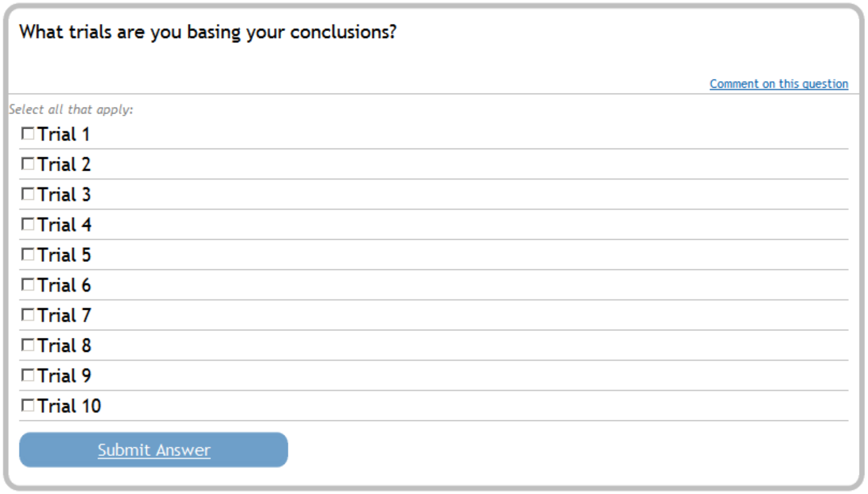
Appendix 14A



Appendix 14B







What trials are you basing your conclusions?

Comment on this question

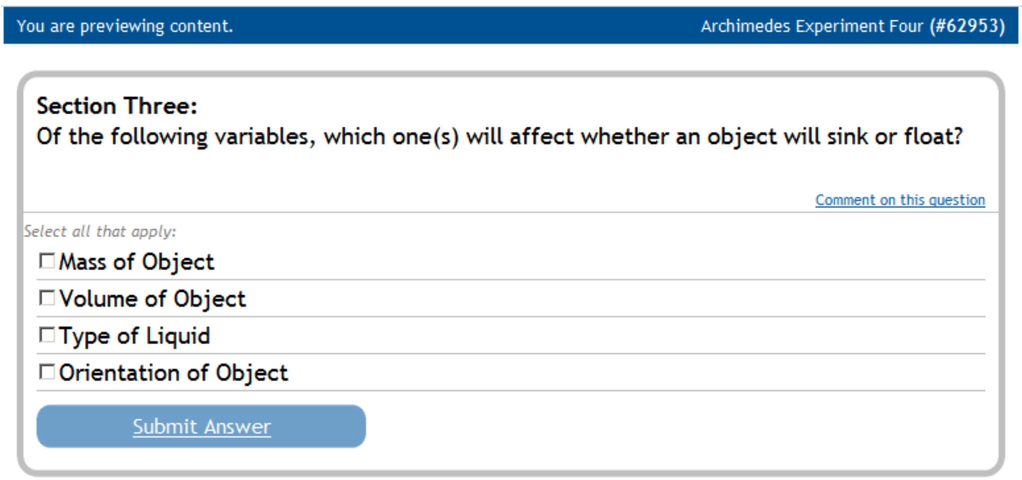
Select all that apply:

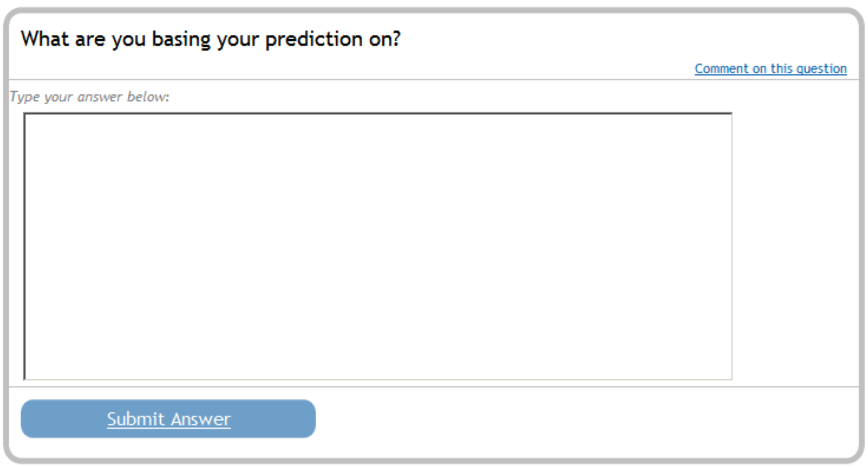
- ☐ Trial 1
- ☐ Trial 2
- ☐ Trial 3
- ☐ Trial 4
- ☐ Trial 5
- ☐ Trial 6
- ☐ Trial 7
- ☐ Trial 8
- ☐ Trial 9
- ☐ Trial 10

Submit Answer

Appendix 15: Microworld 3

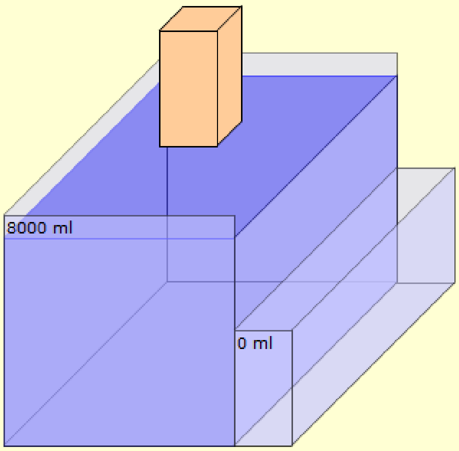
Appendix 15A:





Appendix 15B

Now, test your prediction. Use the drop down menus to change the values of the relevant variables, and then press the "Run Experiment" button to gather data in the table below. Repeat trials as necessary until you have collected enough data to test your prediction.



Drop Object | Reset

Liquid: Water

Object Mass: 50gr

Volume: 100ml

Orientation: Vertical

	Independent Variables				Dependent Variables			Other Data
Trial Number	Liquid Type	Object Mass	Object Volume	Object Orientation	Object Density	Mass Displaced	Volume Displaced	Liquid Density

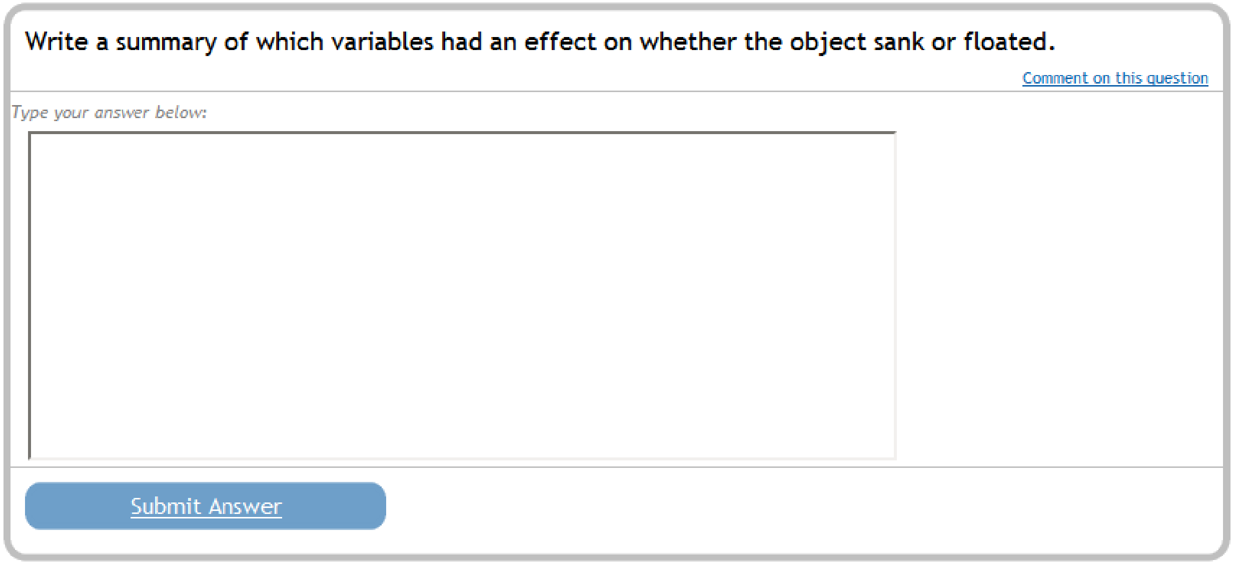
Of the following variables, which one(s) had an affect on whether the object sank or floated?

Comment on this question

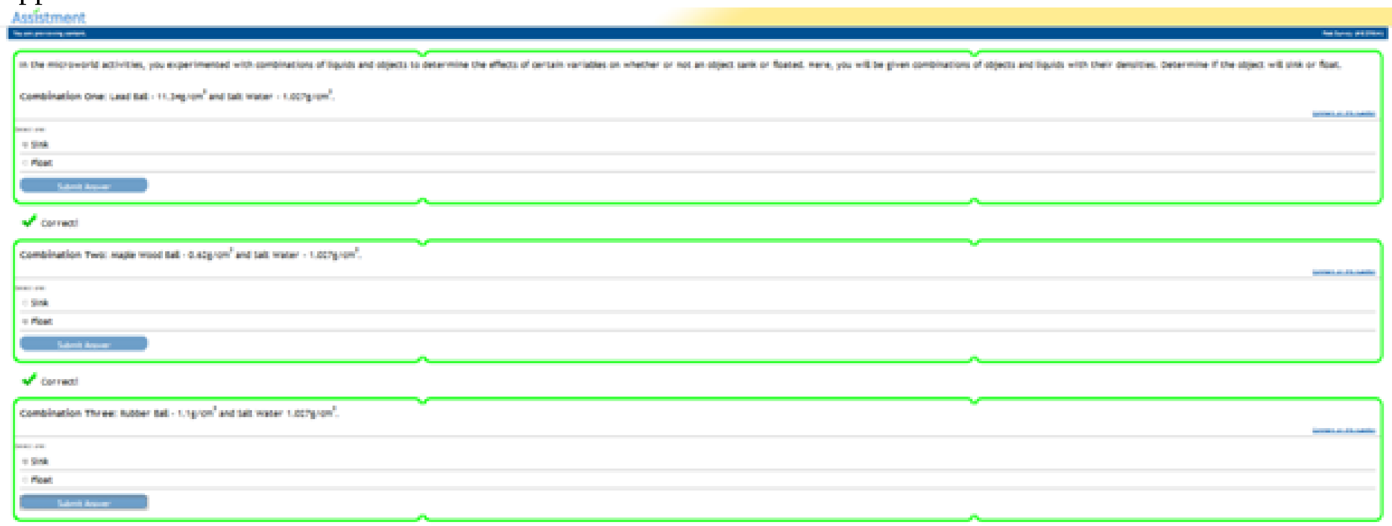
Select all that apply:

- ☐ Mass of Object
- ☐ Volume of Object
- ☐ Type of Liquid
- ☐ Orientation of Object

Submit Answer


Write a summary of which variables had an effect on whether the object sank or floated.
Comment on this question
Type your answer below:
Submit Answer

Appendix 16: Post Test Combinations



Appendix 17: Data Extraction and Analysis Program

Introduction

This appendix is meant as an overview of the program design decisions and implementation details, as such while much of the code contained within this appendix was the actual code used within the program some areas were replaced with pseudo code in order to make the appendix easier to understand. The code that was replaced by pseudo code was specific to how the data was formatted for output and not for the actual analysis of the data.

Input Data

In order to discuss how we extracted the data from the database output first we must explore how the data was structured. At the top level were the courses, which contained one or more assistments, and the assistments themselves contained one or more individual problems. See figure 1.0. The actions performed in the microworlds were contained by problems throughout the assistment. This meant that the actions the students performed within the microworld were stored within the problems that the student was working on at the time they performed the action within the microworld, not necessarily the problem that the microworld appeared in.

Since all the data we needed for analysis is contained within the problems of the assistments, we exported all the problems in each assistment of interest to a text file. An example of the output for a single problem is shown in Figure 1.1:

Figure 1.1

```
row 0
	media_id=['']
	actions=['---
		- - start
		- 1259614890715
		- - widget
```

- 1395
- property_containerB.container
- "<action lasttimediff="0.897"
lastactiontimediff="0.897"
timestamp="1259614970860" who="sim.init"
widget="property_containerB.container"
type="valuechange"><variable current="Narrow"
previous="Narrow"
defrefid="containerB.container"/><variable
current="50" previous="50"
defrefid="containerB.containerWidth"/><variable
current="100" previous="200"
defrefid="containerB.containerHeight"/><variable
current="200" previous="200"
defrefid="containerB.maxVolume"/></action>"
- - answer
- 18151
- true
- Open response text
- - 221630
- 254367
- - end
']
is_correct=['t']
correct=['1']
assignment_type=['ClassAssignment']
tutor_mode=['test']
overlap_time=['18151']
bottom_hint=['']
hint_count=['0']
first_action=['0']
problem_id=['119965']
id=['221630']
incorrect_message=['']
value=['Yes']
teacher_comment=['']
first_response_time=['18151']
answer_id=['221630']
assignment_id=['267288']
attempt_count=['1']
answer_text=['']
tutor_strategy_id=['']
assistment_id=['62950']
user_id=['77758']
position=['1']

```
	end_time=['2009-11-30 16:01:49.049066']
	start_time=['2009-11-30 16:01:30.686716']
	original=['1']
end row 0
```

This structure can be broken down further. The information surrounded by row 0 and end row 0 represents a single problem. The data that takes the form *name = ['value']* can be thought of as attributes to each problem. The actions attribute is particularly interesting as it has the individual answers the student selected for the problem. It also contains the actions the student performed in the microworld while answering that particular problem, represented by the -- *widget* text. These --*widget* actions can appear zero or more times. One for each action the student took within the microworld.

The Lexer and Parser

The lexer and parser are built off the ply module for python.[1]

The lexer

A lexer takes in an input stream and forms tokens out of it according to rules for each token. The tokens for the lexer are as follows:

Figure 2.1

```
# Tokens
reserved = {
	'row' : 'ROW',
	'end' : 'END',
}
tokens = ['ATTRIBUTE_NAME',
 'VALUE_SINGLE',
 'VALUE_LIST',
 'ATTRIBUTE_VALUE',
'ROW_NUMBER'] + list(reserved.values())
```

The tokens and their regular expressions for the input from the database are split into three states. The first, and outermost, set of tokens are for an individual row (i.e. a problem). The tokens defined in this state of the lexer are ROW, END, ATTRIBUTE_NAME, ROW_NUMBER. Below are the definitions for each of these tokens:

Figure 2.2

```
# Initial State
t_ROW_NUMBER = r'\d+'
t_ignore = ' \t\r\n'

def t_ATTRIBUTE_NAME(t):
        r'[a-zA-Z_]+'
        # Check if the data is one of the reserved words.
        t.type = reserved.get(t.value,'ATTRIBUTE_NAME')
        return t
```

The function t_ATTRIBUTE_NAME(t): handles three of the tokens; ROW, END, and ATTRIBUTE_NAME. It does this by checking the value returned by the ply module and checking if it is a key for the reserved words. If the it is not a reserved word then the value returned is considered an ATTRIBUTE_NAME. The function t_EQUALS is also defined in this state and starts the *AttributeValueState*. Since the t_EQUALS doesn’t contain any information beyond telling when a ATRRIBUTE_NAME token stops and its value begins theres no reason for it to be returned to the parser.

Figure 2.3

```
def t_EQUALS(t):
        r'='
        t.lexer.begin('AttributeValueState')
        pass
```

The *AttributeValueState* is used to determine the value of each attribute and allows for them to have various forms of expressing their values. For example dates are can be expressed differently from numbers and text is expressed differently from both dates and numbers. The ATTRIBUTE_VALUE is the only token defined in the *AttributeValueState*. The ATTRIBUTE_VALUE token is defined below.

Figure 2.4

```
def t_AttributeValueState_ATTRIBUTE_VALUE(t):
        r".+(?='\])"
        return t
```

This regular expression for the ATTRIBUTE_VALUE says that take everything preceding a single quote followed by a bracket. The *AttributeValueState* also has the following functions: def t_AttributeValueState_LEFT_BRACKET(t), def t_AttributeValueState_RIGHT_BRACKET(t), and def t_AttributeValueState_START_ACTION_STATE(t) and are defined below.

Figure 2.5

```
def t_AttributeValueState_LEFT_BRACKET(t):
        r"\['"
        pass

def t_AttributeValueState_START_ACTION_STATE(t):
        r'---[ ]'
        t.lexer.begin('ActionState')
        pass

def t_AttributeValueState_RIGHT_BRACKET(t):
        r"'\]"
        t.lexer.begin('INITIAL')
        pass
```

Similar to the previously mentioned def t_EQUALS(t) function these portions of the input provide no useful data besides marking places where a state switch should start or end.

The next state is the *ActionState* and this state handles extracting the values for the actions attribute within a single problem. It has definitions for the tokens: VALUE_LIST, and VALUE_SINGLE see figure 2.6. Both these token definitions also start the *ActionValueState*.

Figure 2.6

```
def t_ActionState_VALUE_LIST(t):
        r"[ ]*-[ ]-"
        t.lexer.begin('ActionValueState')
        return t

def t_ActionState_VALUE_SINGLE(t):
        r"[ ]+-"
        t.lexer.begin('ActionValueState')
        return t
```

The *ActionValueState* is the final state for the lexer. It contains a definition for the ATTRIBUTE_VALUE token, see figure 2.7.

Figure 2.7

```
def t_ActionValueState_ATTRIBUTE_VALUE(t):
        r'.+'
        return t
```

The *ActionValueState* contains the functions; t_ActionValueState_END(t), and t_ActionValueState_NEWLINE(t) shown in figure 2.8. The t_ActionValueState_NEWLINE(t) function determines the end of a single value and returns to the *ActionState*. The t_ActionValueState_END(t) function determines the end of the actions attribute and returns to the *AttributeValueState* which will then returns to the *INITIAL* state.

Figure 2.8

```
def t_ActionValueState_END(t):
        r"[ ]end"
        t.lexer.begin('AttributeValueState')
        pass
def t_ActionValueState_NEWLINE(t):
        r'[\n\r]+'
        t.lexer.begin('ActionState')
        pass
```

The Parser

Firgure 2.9

---

rows -> *row rows* | *empty*
row -> *ROW ROW_NUMBER problem_attribute_list END ROW ROW_NUMBER*
problem_attribute_list -> *problem_attribute problem_attribute_list* | *empty*
problem_attribute -> *DATA_NAME EQUALS problem_attribute_value*
problem_attribute_value -> *VALUE* | *actions_attribute*
actions_attribute -> *LEFT_BRACKET THREE_DASHES list_of_values LEFT_BRACKET*
list_of_values -> *TWO_DASHES VALUE single_value list_of_values* | *empty*
single_value -> *SINGLE_DASH VALUE single_value* | *empty*

As the input is passed through the lexer, the symbols returned by the lexer are then used by the parser in conjunction with the context free grammer(CFG), figure 2.9, to convert the rows of the input into the data structure defined by the class problem shown in figure 2.21.

As the parser finishes parsing each row, the user id is taken from each problem and checked if that student has been created; if the student has not yet been created then a new student is created. After a problem has been assigned to a particular student its assistment id is checked. If the student already contains an assistment with that id the problem is added to that assistment. However, if the student does not contain an assistment with that id, a new assistment is created and the problem is added to the new assistment. The end result of this process is a list of students that looks like list shown in figure 2.10.

Figure 2.10

- Student 943753
    - Assistment 1
        - Problem 1
        - Problem 2
        - Problem 3
    - Assistment 2
        - Problem 4
        - Problem 5

Student 234523
- Assistment 1
    - Problem 1
    - Problem 2
    - Problem 3
- Assistment 2
    - Problem 4
    - Problem 5

An example of the format for the rules used by the parser, and defined in the CFG, are shown in figure 2.11.

Figure 2.11

```
def p_function_1(p):
        # The string below denotes how to build the rule for function_1
from the symbols
        # returned by the lexer and the other rules defined by the CFG
        'function_1 : function_2 function_1'
        # The first function_1 denotes p[0], which is returned to the
function that called this
        # function. function_2 denotes p[1], and the second function_1
denotes p[2].
        # If the string was f1 : f2 f3 f4 f5 then p[0] = f1, p[1] = f2, p[2] =
f3 and so on
        # and so forth. f2, f3, f4 etc can also denote tokens whos values
are returned by
        # the lexer.
        # So p[1] in this case would point to the result returned by
function_2, which would
```

```
        # the value function_2 returned in function_2's p[0], which is then
placed in p[1] for
        # use in function_1 by the ply module.
        function_2_result = p[1]
        # now return function_2_result
        p[0] = function_1_result

def p_function_2(p):
        # returns VALUE in p[0]
        'function_2 : VALUE'
        p[0] = p[1]
```

The parser works by recursion. The parser begins by taking each row and determining which student that row belongs too.

Figure 2.12

```
def p_rows(p):
        'rows : row rows'
        if p[1][0] in students:
            students[p[1][0]].Add_Problem(p[1][1], p[1][2])
        else:
            students[p[1][0]] = student(p[1][0])
            students[p[1][0]].Add_Problem(p[1][1], p[1][2])
        p[0] = students

def  p_rows_empty(p):
        'rows : empty'
        p[0] = []
```

Here the first row is calculated when p_row(p), figure 2.13, is called. After p_row(p) finishes p_rows(p) calls itself until the symbols returned by the lexer no longer match the rule defined by 'rows : row rows.' When this occurs p_rows_empty(p) is called which ends the parsing algorithm.

Figure 2.13

```
def p_row(p):
	'row : ROW ROW_NUMBER attribute_list END ROW
ROW_NUMBER'
	att_list = p[3]
	a_problem = Problem()
	a_problem.media_id			= att_list[0]
	a_problem.Extract_Answers_And_Widgets(att_list[1])
	a_problem.is_correct			= att_list[2]
	a_problem.correct		= att_list[3]
	a_problem.assignment_type		= att_list[4]
	a_problem.tutor_mode			= att_list[5]
	a_problem.overlap_time	= att_list[6]
	a_problem.bottom_hint			= att_list[7]
	a_problem.hint_count			= att_list[8]
	a_problem.first_action			= att_list[9]
	a_problem.Problem_id			= att_list[10]
	a_problem.an_id		= att_list[11]
	a_problem.incorrect_message		= att_list[12]
	a_problem.value		= att_list[13]
	a_problem.teacher_comment		= att_list[14]
	a_problem.first_response_time		= att_list[15]
	a_problem.answer_id			= att_list[16]
	a_problem.assignment_id	= att_list[17]
	a_problem.attempt_count	= att_list[18]
	a_problem.answer_text			= att_list[19]
	a_problem.tutor_strategy	= att_list[20]
	a_problem.assistment_id	= att_list[21]
	a_problem.user_id		= att_list[22]
	a_problem.position		= att_list[23]
	a_problem.end_time		= att_list[24]
	a_problem.start_time			= att_list[25]
	a_problem.original		= att_list[26]
	a_problem.clean()
	user_id = att_list[22]
	assistment_id = att_list[21]
	p[0] = (user_id, assistment_id, a_problem)
```

The p_row function constructs a row by asking the lexer for the following symbols, ROW, ROW_NUMBER, then calling the attribute_list function, and then asking for END, ROW,

ROW_NUMBER from the lexer again. Once the attribute_list is returned a problem object is instantiated and the attributes are then placed within the problem.

Figure 2.14

```
def  p_attribute_list(p):
        'attribute_list : attribute attribute_list'
        p[0] = [p[1]] + p[2]

def p_attribute_list_empty(p):
        'attribute_list : empty_list'
        p[0] = p[1]
```

When the attribute_list function is called it calls the attribute function attribute_list function until no more attributes can be created. At this point the attribute_list_empty function is called, which returns a empty list which is added to the exsisting list which is then returned.

Figure 2.15

```
def  def p_attribute(p):
        'attribute : ATTRIBUTE_NAME attribute_value'
        p[0] = p[2]
```

The attribute function asks the lexer for the ATTRIBUTE_NAME token and then calls the attribute_value function. It then returns the attribute_value functions results.

Figure 2.16

```
def p_attribute_value(p):
        'attribute_value : ATTRIBUTE_VALUE'
        p[1] = clean_up(pattern_map,p[1])
        p[0] = p[1]

def p_attribute_value_no_text(p):
        'attribute_value : empty'
        p[0] = ''
```

```
def p_atttribute_value_action_attribute(p):
        'attribute_value : list_of_values'
        p[0] = p[1]
```

The attribute_value function checks if the next token in the lexer is an ATTRIBUTE_VALUE if there are not it calls the attribute_value_action_attribute function. If the attribute_value_action_attribute function can't be done the attribute_value_no_text function is called which returns an empty string. This gives the attribute an empty value.

Figure 2.17

```
def  p_list_of_values(p):
        'list_of_values : VALUE_LIST ATTRIBUTE_VALUE
single_value list_of_values'
        p[0] = [(p[2],p[3]),] + p[4]

def p_list_of_values_end(p):
        'list_of_values : VALUE_LIST empty_list'
        p[0] = p[2]
```

The list_of_values(p) function retrieves the VALUE_LIST, and ATTRIBUTE_VALUE tokens from the lexer and then calls the single_value function and then the function calls on itself. Once the values from these two function calls are returned they are added the ATTRIBUTE_VALUE and the result is returned.

Figure 2.18

```
def  p_single_value(p):
          'single_value : VALUE_SINGLE ATTRIBUTE_VALUE
single_value'
          p[2] = clean_up(pattern_map,p[2])
          p[0] = [p[2],] +p[3]

def  p_single_value_empty(p):
        'single_value : empty'
        p[0] = []
```

The single_value(p) function askes the lexer for a VALUE_SINGLE, and ATTRIBUTE_VALUE token, and then calls itself until no more single values remain and returns a list of single values.

Classes

Answers

Figure 2.19

```
class Answers:
        truefalse_value = ''
        answer_number = ''
        open_response = ''
        answers = []
        def clean(self):
                p = {'"':'', '\r':'', ' ':''}
                a = []
                for each_answer in self.answers:
                        r = Clean_Up(p, each_answer)
                        if r != '':
                                a = a +[r,]
                self.answers = a
```

The Answers class stores the students answers to each problem, including their true or false value, answer number, open_response, answer selections. This class can be used for multiple choice, select multiple, and open response questions. See the miscellaneous functions for an explanation about the clean function.

Widget

Figure 2.20

```
class Widget:
        def __init__(self, text, number, source):
                self.widget_text = text
                self.widget_number = number
                self.action_source = source
        def clean(self):
                p = {' "&lt;':'<', '&gt;"':'>\n','&gt;':'>\n', '&lt;':'<',
'&quot;':'"', 'row:': 'Trial '}
                self.widget_text = clean_up(p, self.widget_text)
                p = {'\s+':"", '"':"", '\n':'', '\r':'',
'logTrial':"run_experiment", 'drop':"run_experiment"}
                self.action_source = clean_up(p, self.action_source)
        def is_sim_init(self):
                p = re.compile('<action lasttimediff="\d+.\d+"
lastactiontimediff="\d+.\d+" timestamp="\d+" who="sim.init"
widget=".*" type="valuechange">')
                s = p.findall(self.widget_text)
                if len(s) > 0:
                        return True
                else:
                        return False
        def findall_variables(self, variable_hash = {}):
                p = re.compile('<variable current=".*"
previous=".*" defrefid=".*"/>')
                s = p.findall(self.widget_text)
                for each_variable in s:
                        self.extract_variable_data(each_variable,
variable_hash)
        def extract_variable_data(self, variable = '', variables = {}):
                data_regex = re.compile('".*"')
                current_regex = re.compile('current=".*" p')
                defrefid_regex = re.compile('defrefid=".*"/>')
                current_value = current_regex.search(variable)
                if current_value != None:
                        current_value = current_value.group()
```

```
                    current_value =
data_regex.search(current_value)
                    if current_value != None:
                         current_value =
current_value.group()
               defrefid_value = defrefid_regex.search(variable)
               if defrefid_value != None:
                    defrefid_value = defrefid_value.group()
                    defrefid_value =
data_regex.search(defrefid_value)
                    if defrefid_value != None:
                         defrefid_value =
defrefid_value.group()
               p = {'"':''}
               if current_value != None and defrefid_value !=
None:
                    current_value = clean_up(p,current_value)
                    defrefid_value = clean_up(p,defrefid_value)
                    variables[defrefid_value] = current_value
```

The Widget class stores microworld actions and provides functionality to manipulate and extract data from these actions. Its purpose is to allow for analysis of data collected by the microworld and to facilitate reconstructing students activities within the microworld. This class has the following functions is_sim_init, findall_variables, Extract_Variable_Data, and Clean.

The is_sim_init function checks if the action was performed during initialization of the microworld. This function is used to determine which actions are actually performed by the user's interactions with the microworld.

The findall_variables and Extract_Variable_Data functions are used in conjunction with one another to find all the variables that are changed during a particular action and to determine their new values. Using these functions we are able to determine the data that the student had gathered during their microworld experiments. Once the variables and their values have been evaluated they are added to a table that tracks each variable that has been instantiated and it current value. If a variable is already in the table its value is updated with the new result. If a variable is not in the table it is added with its value to the table.

Problem

Figure 2.21

```
class Problem:
    def __init__(self):
        self.media_id = ''
        self.answers = Answers()
        self.is_correct = ''
        self.correct = ''
        self.assignment_type = ''
        self.tutor_mode = ''
        self.overlap_time = ''
        self.bottom_hint=['']
        self.hint_count=''
        self.first_action=''
        self.Problem_id=''
        self.an_id=''
        self.incorrect_message=''
        self.value=''
        self.teacher_comment=''
        self.first_response_time=''
        self.answer_id=''
        self.assignment_id=''
        self.attempt_count=''
        self.answer_text=''
        self.tutor_strategy_id=''
        self.assistment_id=''
        self.user_id=''
        self.position=''
        self.end_time=''
        self.start_time=''
        self.original=''
        self.action_widget = []
    def clean(self):
        pattern_map = {"\["":'',""\]":''}
        self.answers.clean()
        for each_widget in self.action_widget:
```

```
            each_widget.clean()
        self.media_id = clean_up(pattern_map,
self.media_id)
        self.is_correct = clean_up(pattern_map,
self.is_correct)
        self.correct = clean_up(pattern_map, self.correct)
        self.assignment_type = clean_up(pattern_map,
self.assignment_type)
        self.tutor_mode = clean_up(pattern_map,
self.tutor_mode)
        self.overlap_time = clean_up(pattern_map,
self.overlap_time)
        self.bottom_hint = clean_up(pattern_map,
self.bottom_hint)
        self.hint_count = clean_up(pattern_map,
self.hint_count)
        self.first_action = clean_up(pattern_map,
self.first_action)
        self.Problem_id = clean_up(pattern_map,
self.Problem_id)
        self.an_id = clean_up(pattern_map, self.an_id)
        self.incorrect_message = clean_up(pattern_map,
self.incorrect_message)
        self.value = clean_up(pattern_map, self.value)
        self.teacher_comment = clean_up(pattern_map,
self.teacher_comment)
        self.first_response_time = clean_up(pattern_map,
self.first_response_time)
        self.answer_id = clean_up(pattern_map,
self.answer_id)
        self.assignment_id = clean_up(pattern_map,
self.assignment_id)
        self.attempt_count = clean_up(pattern_map,
self.attempt_count)
        self.tutor_strategy = clean_up(pattern_map,
self.tutor_strategy)
        self.assistment_id = clean_up(pattern_map,
self.assistment_id)
        self.user_id = clean_up(pattern_map, self.user_id)
        self.position = clean_up(pattern_map, self.position)
        self.end_time = clean_up(pattern_map,
self.end_time)
        self.start_time = clean_up(pattern_map,
self.start_time)
        self.original= clean_up(pattern_map, self.original)
```

```
        self.answer_text = clean_up(pattern_map,
self.answer_text)
    def Extract_Answers_And_Widgets(self,actions):
        flag = False
        answers = Answers()
        for each_action in actions:
            pattern_map = {' ':'','\r':''}
            s = clean_up(pattern_map,each_action[0])
            if s == "widget":
                number = each_action[1][0]
                source = each_action[1][1]
                text = each_action[1][2]
                widget = Widget(text, number,
source)
                widget.clean()
                self.action_widget += [widget,]
            elif s == "answer":
                answers.answer_number =
each_action[1][0]
                answers.truefalse_value =
each_action[1][1]
                answers.open_response =
each_action[1][2]
                if len(each_action[1]) > 3:
                    answers.answers =
[each_action[1][3],]
                else:
                    flag = True
            elif flag == True:
                answers.answers = [s,] +
each_action[1]
                flag = False
        self.answers = answers
```

The problem class stores the values of each individual problem in the input from the database. It is then used to populate the student and assistment classes. The Extract_Answers_And_Widgets function provides the ability to extract each answer selected and microworld actions performed during the problem. See miscellaneous functions for a description of the Clean function.

Assistment

Figure 2.22

```
class assistment:
    def __init__(self,assistment_number, problem):
        self.assistment_id = assistment_number
        self.problems = [problem,]
        self.microworld_actions = problem.action_widget
    def clean(self):
        for each_Problem in self.assistment_problems:
            each_Problem.clean()
        for each_action in self.microworld_actions:
            each_action.clean()
    def Add_Problem(self, Problem):
        self.problems = [Problem,] + self.problems
        self.microworld_actions = Problem.action_widget +
self.microworld_actions
    def Rebuild_Data_Table(self, user_id):
        microworld_table_rows = []
        CVS_Selections = {}
        Variable_Hash = {}
        mass_right = 0
        mass_left = 0
        Initial_State = {}
        for each_action in self.microworld_actions:
            temp_hash = {}
            if each_action.is_sim_init():

    each_action.findall_variables(Initial_State)
            if each_action.action_source ==
'property_containerA.substance':
                mass_left = 0
            if each_action.action_source ==
'property_containerB.substance':
                mass_right = 0
            if each_action.action_source ==
'run_experiment':
                if mass_right != mass_left:
                    print "Error masses not equal"
                    Variable_Hash['Mass in
Containers'] = "An error occured masses not equal"
```

```
                    else:
                        try:
                            if 'Mass in Containers'
in Variable_Hash:

    Variable_Hash['Mass in Containers'] = str(mass_right * 5)
                        except KeyError:
                            pass
                        for each in Variable_Hash:
                            temp_hash[each] =
Variable_Hash[each]
                        microworld_table_rows +=
[temp_hash,]
                elif each_action.action_source ==
'table.selectCVS.checkboxcolumn':

    each_action.findall_variables(CVS_Selections)
                elif each_action.action_source ==
'addWeightRight':
                    density =
float(Variable_Hash['containerB.density'])
                    if
Calculate_Volume(mass_right,density) < 200:
                        mass_right += 1
                elif each_action.action_source ==
'substractWeightRight':
                    if mass_right - 1 >= 0:
                        mass_right -= 1
                elif each_action.action_source ==
'addWeightLeft':
                    density =
float(Variable_Hash['containerA.density'])
                    if
Calculate_Volume(mass_left,density) < 200:
                        mass_left += 1
                elif each_action.action_source ==
'substractWeightLeft':
                    if mass_left - 1 >= 0:
                        mass_left -= 1
                else:

    each_action.findall_variables(Variable_Hash)
            return
(microworld_table_rows,CVS_Selections,Initial_State)
```

The assistments class stores each problem into its assistment and combines all the actions from each problem into a single list. This allows for the eventual reconstruction of the students actions. The assistment is also given its assistment number. The class provides the following functions Add_Problem, Rebuild_Data_Table, and Clean.

The Add_Problem function adds a single problem to the assistment and adds the microworld actions performed during the problem to a list with the other microworld actions from the previous problems added to the assistment.

The Rebuilt_Data_Table function takes the microworld action list and determines the values of each variable in the microworld and stores those values when the student conducts an experiment. This allows for comparing the students data to their open responses to see if their data matches their response. It also provides the ability to check if a student used the CVS methodoloy during their experiments. But looking at how many of the user modifable variables changed between each trial in the experiment.

See miscellaneous functions for a description of the Clean function.

Student

Figure 2.23

```
class student:
	def __init__(self, student_id):
		self.name = student_id
		self.assistments = {}
	def Add_Problem(self, assistment_id, Problem):
		if assistment_id in self.assistments:

	self.assistments[assistment_id].Add_Problem(Problem)
		else:
			self.assistments[assistment_id] =
assistment(assistment_id,Problem)
```

The student class stores each assistment where the student has completed a problem. This class is for organizing all the problems answered by the student in the input by the problem's assistment id.

Add_Problem takes a problem and checks if a student has the assistment that the problem is a member of, if not then it creates a new assistment object and adds the problem to the new assistment. If the student already has the assistment then the problem is added to that assistment.

Miscellaneous Functions

Figure 2.24

```
def Clean_Up(p,s):
        for each_pattern in p:
                s = re.sub(each_pattern,p[each_pattern],s)
        return s
def clean(self):
                p = {' "&lt;':'<', '&gt;"':'>\n','&gt;':'>\n', '&lt;':'<',
'&quot;':'"', 'row:': 'Trial '}
                self.widget_text = clean_up(p, self.widget_text)
                p = {'\s+':"", '"':"", '\n':'', '\r':'',
'logTrial':"run_experiment",
        'drop':"run_experiment"}
                self.action_source = clean_up(p, self.action_source)
def Calculate_Volume(mass,density):
        return (mass * 5) / density
```

The Cleap_Up function has two inputs p, and s. Input p contains pairs of strings, p_1 and p_2. Input s contains the string to be cleaned. The function then takes each string pair in p and replaces all the instances of p_1 with p_2 in string s.

The Clean function is a class dependent function that uses the Clean_Up function to replace characters in a string with either more meaningful characters or it removes extraneous characters from the string completely. As defined by the pattern variable which contains the string pairs used in the Clean_Up function. Each version of the Clean function is different based on the needs of the individual class, such as which characters to remove and what kind of variables the class contains, for example the problem class also contains instances of the widget class, thus the problem class would call on the widget classes clean function in order to clean its widget instances. The example shown in figure 2.24 is from the Widget class.

Calculate_Volume calculates the volume of the fluid in the balance microworld. It multiplies by five because five grams are added on each click of the add or substract buttons in the microworld. This is a convience function and not a necessary part of the overall program.

Output

The code in iqp_output.py is responsible for creating an organized and clear representation of the data for each student. The data is displayed by student and then by assistment. Since the parse_input() function returns the input already organized in this manner the output function only has to iterate over each student in the collection and then over each assistment the student completed.

Figure 3.0 – Pseudo Code implementation

```
for each_student in hash_of_students:
   if each_student in user_name_hash:
      first_assistment_per_student = True
      assistments = hash_of_students[each_student].assistments
      row_size = 0
      student_header_row = ''
      column_header_row = ''
      columns = ''

      for each_assistment in assistments:
         analysis_results = tuple
         problems = assistments[each_assistment].problems
```

```
        rebuilt_table =
assistments[each_assistment].Rebuild_Data_Table(each_student)
        # adding student name
        if first_assistment_per_student == True:
        first_assistment_per_student = False
          student_header_row += user_name_hash[each_student]
          column_header_row += column_headers_string
        else:
          column_header_row += column_headers_string

        # Adding Assistmen analysis result to columns
        student_header_row += assistments[each_assistment].assistment_id
        analysis_results = assistment_Analysis(rebuilt_table, problems)
        columns += analysis_results

     # All assistments have been analyzed output results
     add_row(student_header_row)
     add_row(column_header_row)
     add_row (columns)
     # Each Student adds 3 Rows.
     row_count += 3
```

The first step for outputting the results is to extract all the information that is to be displayed. First we get all the assistments the student completed. Then for each of these assistments we get all the problems and their answers within the assistment. The assistment then starts to rebuild the trials the student conducted by calling the Rebuild_Data_Table() function on the assistment. This function returns the trials the student conducted and which trials the student claimed to have used the CVS methodology. Once this is completed we pass the rebuilt microworld data table and the assistment problems into the assistment_Analysis() function. See figure 3.1. The assistment analysis function checks which trials a student used the control for variable strategy, determines which trials manipulated an independent variable selected by the student for testing their hypothesis, the total number of trials conducted within the microworld, and the independent variables the student selected. These results are then added to the output for the assistment.

Figure 3.1 – Pseudo code implementation of assistment_Analysis()

```
   Independent_Variables = student_selected_independent_variables

   Microworld_data_table = microworld_data[0]
   CVS_Selections = microworld_data[1]
   Initial_State = microworld_data[2]

   trial_data = check_if_cvs_was_used(Initial_State, Microworld_data_table,
balance_modifiable_variables)

   #stats[0] = Total Trials conducted
   #stats[1] = Total number of trials using CVS
   #stats[2] = The manipulated Variables
   #stats[3] = Trials that correctly tested the student selected independent variables.
   #stats[4] = Total number of trials where a student selected independent variables was
manipulated.

   stats = get_assistment_stats(trial_data, Independent_Variables)
   #output the manipulated variables for each trial
   output(stats[2])

   #  if there was at least 1 trial that correctly tested the student selected independent variable.
   if len(stats[3]) > 0:
      # output the trials that correctly tested the student hypothesis
      output(stats[3])
   else:
     # otherwise state that none correctly tested the student hypothesis
      Output("None")
   # if there was at least 1 trial conducted
   if stats[0] != 0:
     # output the number of trials conducted, the number of trials where the IV was manipulated,
     # the number of trials that the student used CVS, the ratio of CVS trials to total trials, and
The ratio of trials that
     # manipulated a independent variable.
      Output(stats[0], stats[4], stats[1], (stats[1]/stats[0])*100, (stats[4]/stats[0])*100)
   else:
      Output(0, 0, 0, 0, 0)
```

The assistment_Analysis function first determines what variables the student selected as his or her independent variables. This is determined based off the problems within the assistment. For some assistments the IVs are predetermined for the student in others they are retrieved from answers to a problem within the assistment. Once the IV(s) have been determined the function calls the check_if_cvs_was_used function and returns a list of trials. This list includes the following data for each trial: the trial number, the number of variables modified by the student, and what variables were modified. See figure 3.2 for details about the check_if_cvs_was_used function. Once this data has been determined it is passed to the get_assistment_stats function along with the IV(s) selected by the student and returns a tuple containing the following data: The total number of trials conducted, the number of trials that used CVS, the number of trials that manipulated an IV, the manipulated variables for each trial, and the trials that correctly tested a student selected IV. See figure 3.3 for details about the get_assitment_stats function. These results are then output.

Figure 3.1 – check_if_cvs_was_used function

```
def check_if_cvs_was_used(initial_state, list_of_trials, user_variables):
	trial_data = []
	trial_number = 1
	previous_state = initial_state
	for each_trial in list_of_trials:
		change_count = 0
		variables_changed = []
		for each_variable in user_variables:
			try:
				if each_trial[each_variable[0]] !=
previous_state[each_variable[0]]:
					change_count += 1
					variables_changed =
variables_changed + [each_variable[1],]
			except KeyError:
				pass
		previous_state = each_trial
		trial_data = trial_data + [(trial_number, change_count,
variables_changed),]
		trial_number+= 1
```

```
        return trial_data;
```

The check_if_cvs_was_used function compares each trial to the previous trial that was conducted. The first trial that was conducted is compared to the initial state. For each comparison the function counts and records the variables that where modified along with the trial number. A list is constructed for each trial containing these three pieces of data for each trial in the list and is returned.

Figure 3.2 – get_assistment_stats function

```
def get_assistment_stats(trial_data, Independent_Variables):
    # Don't Touch they are the indices for trial_data
    ID = 0
    cvs = 1
    modified_variables = 2

    Trial_Total = 0
    IV_Total = 0
    CVS_IV_Trials = []
    CVS_Total = 0
    Manipulated_Variables = []
    for each_trial in trial_data:
        manipulatedIV = False
        Manipulated_Variables += [“Trial ” + str(each_trial[ID]),]
        for each_variable in each_trial[modified_variables]:
            if each_variable in Independent_Variables:
                manipulatedIV = True
                if each_trial[cvs] == 1:
                    CVS_IV_Trials += ["Trial " + str(each_trial[ID]),]
            Manipulated_Variables += [each_variable,]
        if manipulatedIV:
            IV_Total += 1
        if each_trial[1] == 1:
            CVS_Total += 1
        Trial_Total += 1

    return (Trial_Total, CVS_Total, Manipulated_Variables, CVS_IV_Trials, IV_Total)
```

The get_assistment_stats function looks at each trial and counts the number of trials that used CVS, the number of trials where an IV was manipulated, which trials used CVS and an IV was manipulated, the total number of trials, and keeps track of which variables were manipulated for each trial these results are then returned to the calling function.