CHEMISTRY MICROWORLDS

An Interactive Qualifying Project Report

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Abstract

In this project, the state change microworld activity previously created for Science ASSISTments project, a computer based learning environment that assists students' inquiry as it collects data to assess their performance, was adapted to run in tandem with the state change simulation designed by University of Colorado, Physics Education Technology project (PHET). The microworld and PHET simulation are set up to assess students' domain knowledge of chemistry and their inquiry skills while addressing common misconceptions regarding state change. Through the microworld the students can be assessed on their inquiry skills and content knowledge. Their gain in knowledge through running the microworld will then be assessed through the same pre-test items given in a post-test. The microworld can be implemented in a classroom setting to assess students' knowledge in the future. This project was developed to address whether the PHET simulation, a micro level view of state change processes, deepens students' understanding when used before or after the state change microworld, a macro level view of state change processes.

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Introduction

One of the most important tasks a middle school chemistry teacher can have is remediating misconceptions about chemistry that middle school students have. When anyone is learning something new, the person draws on past experiences and learning to understand new things. Middle school students interpret how the world works through what they have observed in real life before coming into the classroom. However, scientific theories and knowledge are not concurrent with middle school students' conceptions about chemistry (Krajcik, 1991).

Simulations designed to make atoms and other aspects of chemistry easier to visualize for middle school students can introduce misconceptions, due to approximations in diagrams or the fact that we can't actually see atoms even though we may often model them (Trindade, et al 2002). Due to the way simulations can depict matter, many middle school students do not understand that matter is composed of atoms and molecules. In fact, by the time children have reached middle school age they may stop understanding new knowledge about the atomic composition of matter, so they may cease learning and retaining knowledge about matter (Nakhleh et al, 2005). Schools constantly "skill-and-drill" students, resulting with children that can recite scientific terms, pass exams, and balance equations, yet lack a true conceptual understanding of what processes scientific terms are actually describing. Middle school kids can do the math behind chemical equations and use scientific terms, but they do not understand what is really happening underlying all the numbers and terminology (Krajcik, 1991).

In our experiment we want to help remediate misconceptions in chemistry that middle school students have. To do this, we used an environment called Science ASSISTments (www.scienceassistments.org) that tracks student responses, provides guidance as needed, and gives a balance of visual models, experimentation, data collection, and analysis. Science ASSISTments then uses student responses and actions to let teachers know exactly where their students are having trouble learning.

For our project we focused on testing whether a specific simulation, a learning activity that we have built using Science ASSISTments would help increase students' understanding of chemistry on the macro and micro levels of chemistry, and whether showing the simulation, called the "PHET simulation" before or after the state change simulation designed by the Science ASSISTments group would help middle school students develop a better understanding of the micro and macro levels of chemistry. The PHET project (phet.colorado.edu), originally focused on developing physics simulations was named PHET for "PHysics Education Technology" but PHET has later expanded into the fields of chemistry, biology, math, and other areas (University of Colorado, 2011).

Science ASSISTments

The primary tool our group will be using is called Science ASSISTments, and can be found at assistments.org. ASSISTments is a computer-based platform developed by Computer Science Professor Neil Heffernan and his colleagues at Carnegie Mellon University. Janice Gobert, extended the platform to allow for the inclusion and logging of science microworlds for learning and assessment. Science ASSISTments is hosted by Worcester Polytechnic Institute in collaboration with Carnegie Mellon University. One of the Science ASSISTments Professor Gobert and her team developed is the state change microworld that we used in our project. These microworlds and corresponding curricular activities are developed in accordance with the curriculum laid out by the Massachusetts Education Learning Strands. The purpose of Science ASSISTments is to simultaneously test content knowledge and inquiry skills as well as tutor students on inquiry skills. Thus, the program provides teachers with the opportunity to assess their students while students are being assisted with material. Teachers then use the data from Science ASSISTments to better understand where their students need more help with the material being learned. Science ASSISTments use virtual microworlds as a way to engage students in running experiments in a virtual environment. A focus of this project is to promote a more interactive environment, in which students go through cycles of inquiry, testing, and reflecting on their findings. The microworlds engage students to think critically and apply their scientific skills in making hypotheses, designing and experimenting, interpreting data, and communicating results.

Background

Chemistry

Many middle schools use a textbook, such as *Science Integrated Course 3* (Calvo, 2005) that contains many diverse fields, such as biology, physics, and chemistry, subjects that they will learn in their future education. Since most students are going to revisit each subject in high school and learn them in more depth, they are required to learn only the basics of each subject. In chemistry, the basic knowledge that students should have are the difference between elements and compounds, molecular weight and density, and mixtures and substances. According to a literature review that was done by this group, these are the topics that can often confuse students.

Everything that students can see on the periodic table, such as H (hydrogen), O (oxygen), Na (sodium), Hg (mercury), Au (gold), etc. are called elements and they cannot be chemically broken down into simpler substances. If two or more of those elements are combined in definite proportions, then they become a compound. Water (H2O), sugar ($C_6H_{12}O_6$), salt (NaCl), hydrogen peroxide (H2O2), etc. are examples of compound.

Also there are substances and mixtures. In chemistry, a substance is defined as a form of matter with constant chemical composition and characteristic, and it is impossible to separate it by physical methods. To distinguish from a mixture, a chemical substance is often called pure. For example, pure water, sugar, and salt are classified as chemical substances. However, when those substances are mixed without causing chemical reaction, then they are called mixtures. For example, if salt and water are mixed together, it simply becomes salt water. There is no chemical reaction such as breaking bonds between two elements in one substance.

Each element has a specific weight called its atomic mass**,** or the average mass of an element's atoms, and is represented by the number under each symbol on the periodic table. No two elements have the same atomic mass. Atomic mass is calculated based on one mole of each element; therefore the number of moles can be calculated based on the amount of substance. Another property of matter that involved mass is density. Density of a substance is defined as the ratio of its mass to its volume (density = m / V for example 1 gram of water has a volume of 1 cm3 thus water has a density of 1.00 g/cm3 at 20C. Conceptually an important difference between mass and density is that density is constant regardless of the amount of substance, where mass depends on the amount. For example, if you have 50g of water and 100g of water, both at 20C, they will have a density of 1.00g/cm3, but one has a mass of 50g and the other has a mass of 100g.

These basic concepts are important in understanding further topics in chemistry, and are related to the misconceptions of students.

Misconceptions

There are a great deal of misconceptions that middle school students hold that need to be addressed by teachers all over the world. It has been shown that misconceptions in chemistry among middle school students do not differ by the country the students live in. Students from three different countries used similar reasoning regarding the sub-microscopic levels and the macroscopic levels of chemistry (Onwu & Randall, 2006).

Children have difficulty differentiating between mass, weight, and density. Most 8 and 9 year olds believe that all matter, including atoms, must have some weight, yet they cannot understand just how miniscule the weight of a single atom really is. They see matter as how it is plainly seen with the naked eye: an assortment of a bunch of materials that are all visible and occupy space. It is difficult for students to understand what they cannot see, which has led to the increase in popularity of using visual models and simulations. However, students still see atoms as something within matter rather than the building blocks they really are (Wiser & Smith, 2008).

When it comes to differentiating between mixtures and substances, middle school children have difficulty understanding that when two liquids mix, such as water and alcohol, the volume of the mixture is not always the sum of the two liquids' initial masses. In fact, liquids intermix, masses add, but volumes do not add. It is possible for volume to increase or decrease when mass stays the same, and this crucial understanding is missed (Snir et al, 2003).

Misconceptions in elements and compounds include heating copper with sulfur. Many middle school students do not know that heating those two substances leads to forming a new substance. What is important about this formation is that sometimes there is leftover copper or sulfur residue, and copper sulfide can only be created using the right amounts of copper and sulfur.

Mass is conserved across the reaction. Yet many children think volume would instead be conserved, and when they saw the leftover copper or sulfur they were confused as to why there was something leftover (Snir et al, 2003).

Middle school students cannot consistently explain properties of matter or material processes using their knowledge of the composition of materials. Their ideas about composition of matter contain fragmented ideas that prevent them from acquiring a complete understanding about the composition of matter (Nakhleh et al, 2005). Students do not get the foundation of understanding in chemistry that they need to learn more advanced topics. Middle school students also see matter as being made of a continuous, space filling, and static medium when in fact it is made of discrete particles that are in motion and have space between them. Students do not understand that matter is made of particles that are in a constant motion and can react with each other by breaking and forming bonds (Nakhleh, 1992).

It has been found that middle school students are unable to consistently explain material properties and processes, hold consistent concepts about materials, or relate the microscopic levels of chemical changes in materials to their macroscopic behavior (Nakhleh et al, 2005).

From the beginning, middle school students do not build a competent understanding of fundamental chemical concepts, and this makes them unable to learn advanced concepts that instructors rush to teach. Furthermore, students are simply uninterested about learning about the changes in substances; they take the changes at face value and assume that things are "just that way", lacking a scientific explanation. Many students mistake new substances for what is really just an old substance in a new form. They also do not understand that matter is made of particles that are in constant motion and react by creating and breaking chemical bonds (Nakhleh, 1992).

Students have difficulty telling the difference between weight and density and do not understand that even very small pieces of matter have weight. What cannot be seen is even more complicated to explain, and because of this students do not understand the nature, behavior, or structural arrangement of atoms (Wiser & Smith, 2008). This leads to the inability to link submicroscopic models with macroscopic events or demonstrate a consistent reasoning of how particles build matter (Onwu & Randall, 2006).

When it comes to terminology, students can recite them without understanding their underlying meaning, which demonstrates a lack of understanding of basic chemical concepts. Equations can be solved and balanced, yet their significance in demonstrating what is happening in a chemical reaction is lost to students. In addition middle school students have trouble differentiating between temperature and heat energy, and the properties of a substance and the properties of a single atom. This shows that middle school students cannot relate phenomena to concepts (Krajcik, 1991).

Difficult concepts for students to understand are that when two liquids mix, such as water and alcohol, the volume of the mixture may be less than the sum of the two individual initial volumes of the water and alcohol. Volumes do not necessarily add, yet masses do, and this is a distinction that students do not understand. In another example, when a metal ball is heated its volume increases and its mass stays the same and students are puzzled as to why this is because they do not understand the conservation of mass. Another situation is when copper and sulfur are heated together to make copper sulfide there is some leftover residue of one substance or the other, and this is because only certain amount of each substance when heated makes the new substance, and students wonder why there would ever be leftover residue with this kind of reaction (Snir et al, 2003).

Another misconceptions for middle school students is that they think matter is made of a continuous medium that in static and is always taking up some sort of physical space. Molecules are imagined to be much larger than they really are. They think molecules of the same substance can vary in size and vary shape in different phases that atoms are alive, molecules will expand when heated, water molecules are made of solid spheres like they are depicted as in some diagrams, and that pressure affects the shape of a molecule (Nakhleh, 1992).

Middle school students think that air is not matter and that atoms are a property of matter as opposed to the building block of matter they really are (Wiser & Smith, 2008). They think chemical reactions are reactants adding together to form new materials rather than a process of bond breaking and bond formation (Krajcik, 1991). They also believe that volume is conserved across chemical reactions (Snir et al, 2003).

These are only a few misconceptions that middle school students have about chemical processes. The underlying message gathered from these misconceptions is that middle school students lack a cohesive understanding of the micro-level and macro-level processes in chemistry, and have trouble differentiating the two, leading to the development of more misconceptions when they try to learn more advanced topics in chemistry.

Massachusetts Education and Learning Strands

For our project we focused on four strands of the Massachusetts Science and Technology/Engineering Curriculum Framework that instructors are supposed to follow when they teach middle school physical science. They are numbers 5 through 8 under the Physical Sciences section for grades 6-8. Strand 5 says that students should be able to recognize over 100 of the elements that can combine in various ways to produce compounds that make up matter. This can be done through using atomic models to show how the atoms combine and conserve mass. Strand 6 says that students should be able to differentiate between an atom and a molecule, and that using atomic models to build molecules would assist in that understanding. Strand 7 is simply naming basic examples of elements and compounds, and this is what schools excel at through their uses of labs and lectures, so we did not need to focus on this strand for our project. Finally, strand 8 says that middle school students should be able to differentiate between mixtures and pure substances. Unlike the other 3 strands, there are no examples on how teachers can teach students this. As we have seen from our research on student misconceptions, students need help learning strands 5, 6, and 8 (Massachusetts Department of Education, 2006).

Students in grades 6 through 8 are still developing their sense of using real-world experiences to learn chemical and physical behavior, so it is crucial that they get those experiences in middle school in order to support later understanding as is necessary in high school chemistry. It is in the middle school grades that students must learn to distinguish volume, mass, motion, energy, and other concepts or else they will develop misconceptions if these topics are not introduced in the proper way that lessens the potential for misconceptions.

Goals

The goal for this experiment is to design an activity that could be used to address middle school students' misconceptions in chemistry. The research we have conducted shows that middle school students lack a micro-macro level of understanding in chemistry. In the design of our activity, one group of students will use the PHET simulation before the state change of matter simulation that was created for Science ASSISTments and the other group will use the PHET simulation after the state change of matter simulation. We will then assess the students with pre- and post-tests and determine which group developed a better understanding of the concepts described in the simulations. Since our pre- and post-test questions address micro- and macro-level concepts, if there is a benefit to learning the micro-level before the macro-level, students in this condition might perform better than the students in the condition in which the macro- is presented before the micro.

Methods

Participants. These activities were designed for middle school students from Massachusetts; however, collecting data on this project was not possible.

Materials

The following section describes the pre-test and post-test as well as the State Change microworld and PHET simulation. The States of Matter PHET simulation can be found at http://phet.colorado.edu/ as well as in Appendices 9-12.

Pre-Tests

Content Knowledge Pre- and Post-Test (Appendices 1-5)

Objective

The content knowledge tests were developed to gain an understanding of students' knowledge of boiling point and melting point of water as well as what happens to molecules of matter as they undergo phase changes. In addition, this also assesses the students on any misconceptions with regard to phase change and whether or not the microworld will improve their understanding of the characteristics of molecules in different phases. The pre-test is given to the students before they enter the PHET simulation (or microworld) to gain a preliminary understanding of their knowledge before completing the experiment. The post-test contains the same questions as the pre-test. The post-test is given to gain an understanding of what the students learn after running the experiment.

Content Pre-Test
The content knowledge pre-test consists of ten multiple choice questions on phase change and focuses on misconceptions that middle school students have as identified in the literature that we reviewed.

Content Pre-Test 1 (Appendix 1a)
Question one focused on the students' previous knowledge of the melting point of water. This question is not directly addressed in this project. This question came from the pre-test Professor Gobert's team used when testing the state change microworld.

Content Pre-Test 2 (Appendix 1b)
The second question focused on the students' previous knowledge of the boiling point of water. In our state change microworld the student is assessing whether the boiling point of water changes when the amount of hear/substance is manipulated. This question came from the pre-test Professor Gobert's team used when testing the state change microworld.

Content Pre-Test 3 (Appendix 2a)
Question three is a targeted question from a student misconception that the amount of heat applied to a substance affects its boiling point. This is directly assessed in the microworld. One of the hypotheses the student has to develop and test is whether the amount of heat will change the boiling point of water. This question came from the pre-test Professor Gobert's team used when testing the state change microworld.

Content Pre-Test 4 (Appendix 2b)
Question four is a targeted question from a student misconception that the amount of a substance will affect its boiling point. This is directly assessed in the microworld. One of the hypotheses the student has to develop and test is whether the amount of substance will change the boiling point of water. This question came from the pre-test Professor Gobert's team used when testing the state change microworld.

Content Pre-Test 5 (Appendix 3a)
Question five is a targeted question of the PHET simulation. It focuses on states of matter generalizations and asks students to identify the densest state of matter. In other words the state of matter with atoms packed tightly together. This knowledge can be obtained when the student looks at the molecules in each state of matter in the simulation.

Content Pre-Test 6 (Appendix 3b)
Question six is a targeted question of the PHET simulation. It focuses on states of matter generalizations and asks students to identify the least dense state of matter. In other words the state of matter with atoms that move freely. This knowledge can be obtained when the student looks at the molecules in each state of matter in the simulation.

Content Pre-Test 7 (Appendix 4a)
Question seven is a targeted question of the PHET simulation. It asks which state of matter has the least energetic molecules or molecules that move slowly. In the PHET simulation the student makes a hypothesis of whether the water molecules gain or lose energy when heated. The student can click to change the state of matter and observe the movement of the molecules in that state.

Content Pre-Test 8 (Appendix 4b)
Question eight is a targeted question of the PHET simulation. It asks which state of matter has the most energetic molecules or molecules that move quickly. In the PHET simulation the student makes a hypothesis of whether the molecules gain or lose energy when heated. The student can click to change the state of matter and observe the movement of the molecules in that state.

Content Pre-Test 9 (Appendix 5a)
Question nine gives the students a relatable real world situation. It is a targeted question of the PHET simulation. It covers the misconception that molecules get smaller as they freeze. In the PHET simulation the student can manipulate the temperature gauge and observe what happens to the molecules as the temperature decreases. This targets the knowledge the student gains while observing the water molecules in the PHET simulation.

Content Pre-Test 10 (Appendix 5b)
Question ten gives the students a relatable real world situation. It is a targeted question of the PHET simulation. It covers the misconception that molecules get bigger as they are heated, in this case, they melt. In the PHET simulation the student can manipulate the temperature gauge and observe what happens to the molecules as the temperature increases. This targets the knowledge the student gains while observing the water molecules in the PHET simulation.

Data Collection Overview

After students sign into the Science ASSISTments website they complete the pre-test, designed as part of this IQP, to determine their general knowledge of chemistry states of matter. This contained questions first on how the amount of heat and amount of substance affect the boiling point of a substance and then questions on how temperature affects the movement of molecules. After completion of the pre-test students are then introduced to the state change microworld and PHET simulation. In these activities students are asked to form a hypothesis and test their hypothesis by manipulating variables. After completion of each activity the student completes a data interpretation to further analyze what the student has learned after interacting with the activity. Finally, students complete a post-test. This is an exact copy of the pre-test to gauge if their knowledge has changed after the completion of the microworlds.

Chemistry Microworlds and Tasks

Microworld One: Phase Change (Appendix 6-8)

Objective

Professor Gobert and her team previously created the original microworld for State Change. For our IQP we focused on only a few aspects in this microworld. In this microworld we are focusing specifically on the relationship between the amount of heat/substance and its effect on the boiling point of water. Pre-test questions one through four focus on this microworld. For students who hold the common misconception that the amount of a substance or the amount of heat applied to a substance will change of boiling point of that substance, this microworld will assist by providing guided experimentation. For those already familiar with the topic, the microworld will reinforce their understanding.

Task 1: Amount of Heat/ Boiling Point

After completing the pre-test the student is directed to the microworld. The first section of the microworld allows the student to explore and familiarize him/herself with the structure of the microworld. This lets the student become comfortable with the controls without the necessity of manipulating specific variables or measuring specific changes.

After experimenting with the microworld, the student is prompted with a pop up window directing them to build a hypothesis using a widget that will specify the students' notion of the relationship between the amount of heat and the water's boiling point. The structure of the hypothesis builder is as follows: If I change the [amount of ice, size of container, amount of heat, time the ice takes to melt, time the water takes to boil] so that is [decreases, increases] the [time the ice takes to melt, time the water takes to boil, melting point of ice, boiling point of water, amount of ice, size of container, amount of heat] [decreases, increases, will not change].

After choosing the correct variables from the set of pull downs, the student will test their hypothesis by using the microworld. It is up to the student to change the correct variables to observe the effect; in this case, the student should only be changing the amount of heat. The student may also change the container size and amount of ice; however neither of these will "prove" their hypothesis. These are the independent variables. The variables that the student can observe but not change are the dependent variables. The dependent variables are the melting point, boiling point, melting time, and boiling time. The student must do a minimum of two trials to observe the affect that changing the amount of heat has on the boiling point. The student may change the amount of heat from high to medium to low. The results of the student's trials can be seen in a table at the bottom of the page. The table lists the results by trial number followed by each independent variable (container size, amount of heat and amount of ice) and dependent variable (melting point, boiling point, melting time, and boiling time).

By changing the specific variable and watching its effects upon the boiling point, the student is then ready to analyze their previously created hypothesis by creating a "data interpretation", which is identical to the structure of the hypothesis builder. The structure of the data interpretation is as follows: When I changed the [amount of ice, size of container, amount of heat, time it takes ice to melt, time it takes water to boil] so that it [decreased, increased], the [time the ice takes to melt, time the water takes to boil, melting point of ice, boiling point of water, amount of ice, size of container, amount of heat] [increased, decreased, did not change]. This means my data [does not support, support] my hypothesis. The student then drags trials used to support their analysis to the evidence table. After this, the student has the option of building and analyzing as many hypotheses as they wish in addition to running as many trials as needed to fully grasp the relationship between amount of heat and boiling point. The student is also given the option to move on at this point.

Task 2: Amount of Ice/ Boiling Point

The second part of the first microworld is based of the relationship of the amount of ice and boiling point. In structure, the second part of the microworld is identical to that of the first. The only differences are that the student is now building a hypothesis to test the relationship between the amount of ice and the boiling point instead of the amount of heat and the boiling point. The microworld itself is identical except for the desired variable manipulation; being amount of ice instead of amount of heat. Once again the student is asked to build a hypothesis, test it, and analyze the results.

PHET Microworld: Exploration of PHET State Change Simulation (Appendix 9-12)

Objective

The objective of the second microworld is to solidify the understanding of the states of matter. This microworld includes a PHET simulation made by the University of Colorado at Boulder. In this simulation the students are able to manipulate the temperature, atoms and molecules (neon, argon, oxygen, and water), and state (water, liquid, gas). The activity is designed to improve common misconceptions and build comprehension about the movement of water molecules as they are heated /cooled.

Task 1: Heat/Molecule Movement

The experiment starts like the first microworld directing the student to build a hypothesis. On the left of the window a still image of the PHET simulation is shown. The image shows water molecules being heated. The student is directed to build a hypothesis regarding what will happen to the water molecules as they are heated. The structure of the hypothesis builder is as follows: If the water is [heated, cooled] then the water molecules will [gain energy, lose energy] and [move faster, move slower].

After choosing from the set of pull downs, the student will then test their hypothesis using the PHET simulation and changing specific variables to observe the effect; in this case the student must change the atoms/molecules to water and increase the heat. Before the student is brought to the PHET simulation, they are provided with a set of directions. These directions tell the student that they will be seeing a simulation that shows how water behaves when it is in different states of matter. The student must select water and can then select liquid, solid, or gas to observe the pattern and movement of molecules in each state. They will use the slider below the beaker to heat up or cool the container to see how the molecular behavior of water changes as it transitions between states of matter. They must hold the slider in the position they want it (heat/cool) and observe what happens to the molecules for at least fifteen to twenty seconds. Once they read the directions they can then move on to testing their hypothesis. They may do this by using the slider below the beaker to heat up the water and how the molecular behavior changes.

Once the student has played with the simulation, they can then click the "I am done" button. Once they do this they are ready to analyze their previously created hypothesis by creating a "data interpretation". This interpretation is identical is structure to the hypothesis widget. The format is as follows: When water was [heated, cooled] the water molecules [gained energy, lost energy] and [moved faster, moved slower]. If the student is still unsure of what happens to the water molecules as they are heated they may go back to the experiment window and continue manipulating the simulation. If they are confident that they have learned the material they may also move on at this point.

Unit & Experimental Conditions

The main focus we are looking at with our project is whether providing the students with the PHET simulation (which focuses on the micro level of chemistry) before or after the state change simulation (which focuses on the macro levels of chemistry) will give students a better understanding of the chemical processes that take place when matter changes states.

Our experiment has two conditions. Our first condition is that the micro level (the PHET simulation) is presented before the state change simulation. We will run the pre-test and then present students with the PHET simulation. Students will observe the state change of water at the molecular level and hypothesize if the molecules will move faster or slower and gain or lose energy when heated. After running the simulation and interpreting the data, the student will then be presented with the state change microworld. The microworld describes the same process of water changing states of matter with the exception that the students will observe the process at the macro level. In this microworld, the student is looking at whether the amount of substance and the amount of heat affect the boiling point of that substance. They will collect data about this and interpret the data to decide if these things affect the boiling point of water. The other group of students will go through a similar procedure with the exception of being presented material from the macro level of chemistry before the micro level, simply meaning that the student will first conduct inquiry with the state change microworld and then the PHET simulation. The ordering of the materials and the overall curricular design of the activity is depicted in the table below.

Table 1. Experimental Design.

	Condition 1	**Condition 2**
Step 1	Pre-test (same for both conditions)	
Step 2	PHET Simulation	Chemistry Microworld
Step 3	Chemistry Microworld	PHET Simulation
Step 4	Post-test (same for both conditions)	

By providing the PHET simulation first, the students see on a micro level (atomic or molecular level) what is happening to water as it is heated. The student sees a microscopic view of water molecules moving in a beaker. The molecules in the beaker will either move faster and more freely or slower and less freely depending on if the student increases or decreases the temperature. This is compared to the state change microworld in which information is shown on a macro level; this means the data is directly observable. As the ice is heated in the beaker the student sees the data results in a table. More relevant to our project, the student sees the boiling point of water as they increase the amount of substance or amount of heat.

As previously described in the section on students' misconceptions, students have difficulty with micro-macro learning because they have difficulty relating macroscopic properties and microscopic models as well as seeing microscopic models as relevant in explaining the world they live in (Nakhleh 2005).

As it was beyond the scope of the current project to test this experimental manipulation, in the future, the two orderings of these virtual materials could be tested with students in order to examine whether the students understand the subject better when being introduced to the micro level before or after the macro.

Research Design & Plan for Data Collection

In order to test out this activity, our group planned to visit Sherwood Middle School in Shrewsbury, Massachusetts. There we would run the activity with three different classes of fifth grade students. Each class of students would be randomly divided into two groups by the Assistmtents system; one group would run the PHET simulation and then the state change microworld. The other group of students would do the opposite, running the state change microworld and then the PHET simulation. The steps of each activity are described in the table below. In "condition 1" the student runs the simulation before the microworld, in "condition 2" the student does the opposite. See Table 1 above. This would allow our group to test how giving the students a micro view of chemistry before or after a macro view affected their understanding. Due to time constraints [1], our group was not able to collect data and feedback from students. However, we were able to make some hypotheses about the outcome based on the previous literature in the field of micro/macro understanding of chemistry.

Students' overall understanding, collapsing over condition, would be assessed based on how the students performed on the pre- and post-tests. The questions for the pre and post-tests are the same. After running the activity, hypothetically, the students would perform better on the post-test when compared to the pre-test. We could then further analyze the data to see if students that were randomly assigned to the "condition 1" vs. "condition 2" group performed better on the post-test and vice versa.

Based on our previous research we hypothesized that the students in condition 1 will perform better on the post-test than those students in condition 2. The students would perform better

[1] Data collection was cancelled due to a family emergency for Dr. Gobert.

because they would first see what was happening to the water on a micro level. They would see the molecules moving in the beaker and understand that the water molecules would move faster and more freely as the water was heated. They would not yet be given the macro view and therefore not have the previous assumptions when viewing the microworld. Once they understand the micro view, we hypothesize that they would better support students' understanding of the macro-view.

Conclusion

The goal of the project was to design and develop this activity for middle school students schools that they could achieve a deeper understanding in chemistry by supporting their understanding of the micro- and macro-processes involved in state changes some misconceptions that they may already have.

Our activity was designed in two different ways, and based on our estimated outcome of the experiment, we believe its design is better than the existing microworld for a few reasons. For condition 1, by adding the PHET simulation prior to the chemistry microworld activity, students can get an idea of what is happening on the molecular level during phase change before they conduct the experiment with the microworld. The post-test, which contains the same questions as the pre-test, helps teachers as well as students to assess themselves to see if they actually learned the information that was presented in the simulation. If the students did not acquire the information and do not answer more questions correctly on the post –test compared to the pre-test, they may go back and try the activity again.

The main focus of the group while creating this activity was what type of design and pre/post-test questions would help students deepen their understanding of phase change. While we as a group were unable to test this activity with students, we believe that once it is tested, it has the potential to become a very useful chemistry learning activity for students at this level.

References

Calvo, Cutler T. (2005). *Integrated Course 3.* Evanston, IL: McDougal Littell.

Krajcik, Joseph S. (1991). *Developing Students' Understanding of Chemical Concepts.* In Glynn, S. H., Yeany, R. H., & Britton, B. K. (Eds.). *The Psychology of Learning Science.* Hillsdale, NJ: Erlbaum.

Massachusetts Department of Education. (2006) Massachusetts Science and Technology/Engineering Curriculum Framework. http://www.doe.mass.edu/frameworks/scitech/1006.pdf

Nakhleh, Mary B. (1992). Why some students don't learn chemistry: Chemical misconceptions. *Journal of chemical education, 69*, 191-196.

Nakhleh, M. B., Samarapungavan, A. and Saglam, Y. (2005), Middle school students' beliefs about matter. *Journal of Research in Science Teaching, 229*, 357-358.

Onwu, Gilbert O. M. and Randall, Elize. (2006, Sept 15) Some aspects of students' understanding of a representational model of the particulate nature of matter in chemistry in three different countries. *Chemistry Education Research and Practice*, *7(4)*, 226-239. Retrieved from http://www.rsc.org/images/Onwu%20paper_tcm18-66591.pdf

Snir, Joseph, Smith, Carol L., and Raz, Gila. (2003, Nov) Linking phenomena with competing underlying models: A software tool for introducing students to the particulate model of matter. *Science Education*, *87*, 794-830. Retrieved from http://au4sb9ax7m.scholar.serialssolutions.com/?sid=google&auinit=J&aulast=Snir&atitle=Linking+phenomena+with+competing+underlying+models:+A+software+tool+for+introducing+students+to+the+particulate+model+of+matter&id=doi:10.1002/sce.10069&title=Science+%26+Education&volume=87&issue=6&date=2003&spage=794&issn=0926-7220

Trindade, Jorge, Fiolhais, Carlos, and Almeida, Leandro. (2002) Science learning in virtual environments: a descriptive study. *British Journal of Educational Technology, 33(4*), 471.

Tro, Nivaldo J. (2011). *Chemistry: A Molecular Approach*. Upper Saddle River, NJ: Pearson Prentice Hall.

University of Colorado (2011). States of Matter: Basics. Retrieved May 12, 2012, from http://phet.colorado.edu/en/simulation/states-of-matter-basics

Wiser, Marianne and Smith, Carol L. (2008, Jun 18). Learning and Teaching about Matter in Grades K-8: When Should the Atomic-Molecular Theory Be Introduced? *The International Handbook of Conceptual Change*, 205-239.

Appendices

Appendix 1a: Content Pre-Test

At what temperature does ice melt?

Comment on this question

Select one:

- 100°C
- 0°C
- 50°C
- -10°C

Submit Answer

Appendix 1b: Content Pre-Test

At what temperature does water boil?

Comment on this question

Select one:

- 100°C
- 200°C
- 0°C
- 32°C

Submit Answer

Appendix 2a: Content Pre-Test

Does the amount of heat applied to water affect its boiling point (after the ice has melted into water)?

Comment on this question

Select one:

- Yes, it raises it
- Yes, it lowers it
- No
- No, but it affects the ice's boiling point

Submit Answer

Appendix 2b: Content Pre-Test

Does the amount of ice affect the water's boiling point (after the ice has melted into water)?

Comment on this question

Select one:

- Yes, it raises it
- Yes, it lowers it
- No
- It sometimes changes the boiling point

Submit Answer

Appendix 3a: Content Pre-Test

Of gases, liquids, and solids, what is the most dense state of matter?

Comment on this question

Select one:

- Solids
- Liquids
- Gases
- Plasma

Submit Answer

Appendix 3b: Content Pre-Test

Of gases, liquids, and solids, what is the least dense state of matter?

Comment on this question

Select one:

- solid
- liquid
- gas
- plasma

Submit Answer

Appendix 4a: Content Pre-Test

Which of the following has the least energetic molecules?

Comment on this question

Select one:

- solids
- liquids
- gases
- plasmas

Submit Answer

Appendix 4b: Content Pre-Test

Which of the following has the most energetic molecules?

Comment on this question

Select one:

- solids
- liquids
- gases
- crystals

Submit Answer

Appendix 5a: Content Pre-Test

You fill a popsicle mold with orange juice and put it in the freezer. After a few hours the orange juice freezes and a popsicle forms, what happens to the molecules as the orange juice freezes?

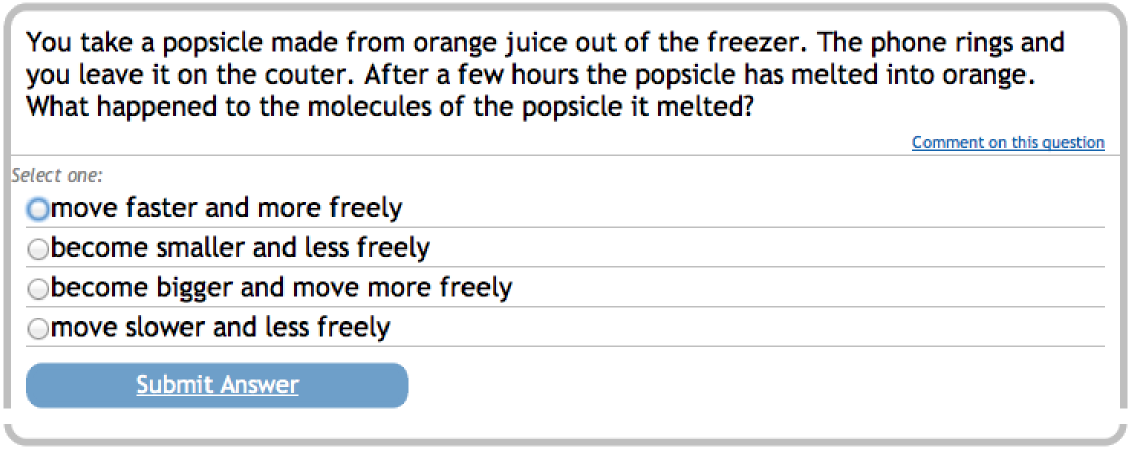
Comment on this question

Select one:

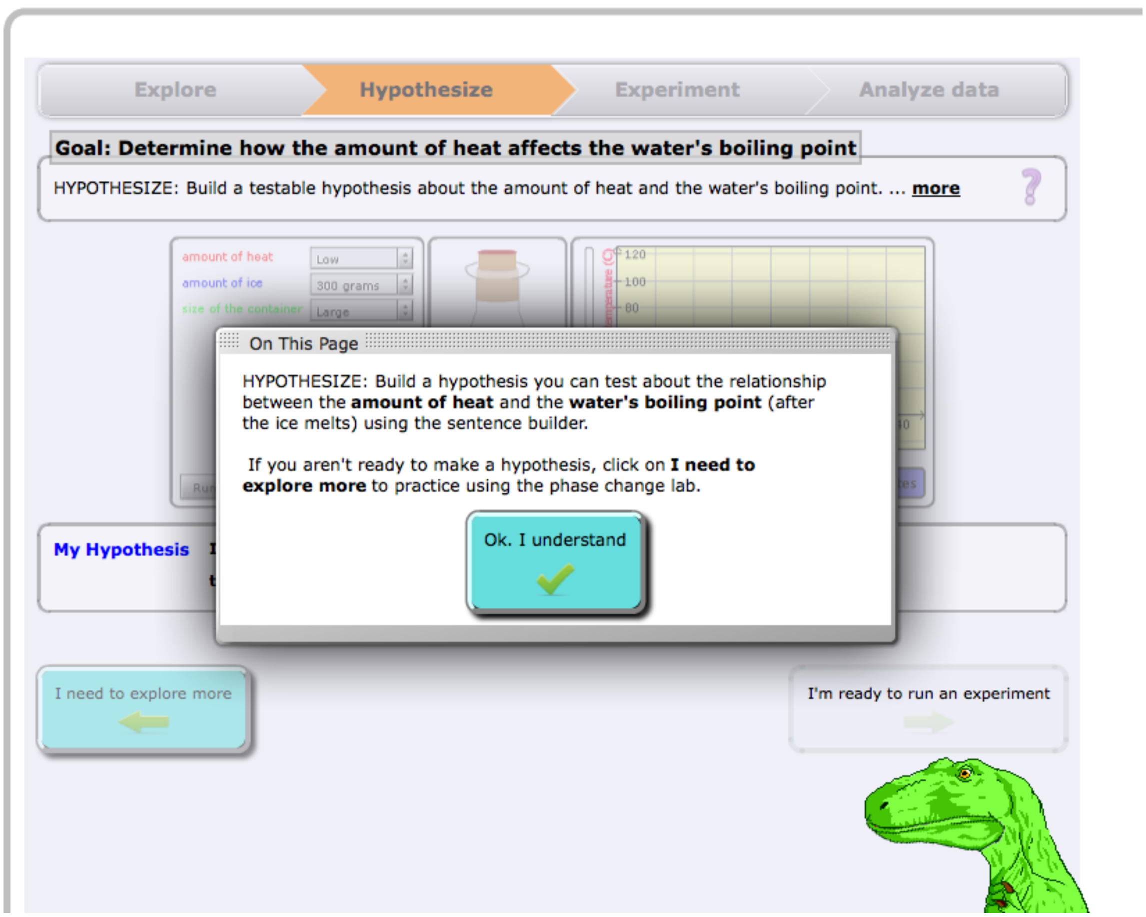
- move faster and more freely
- become smaller and move less freely
- become bigger and move more freely
- move slower and less freely

Submit Answer

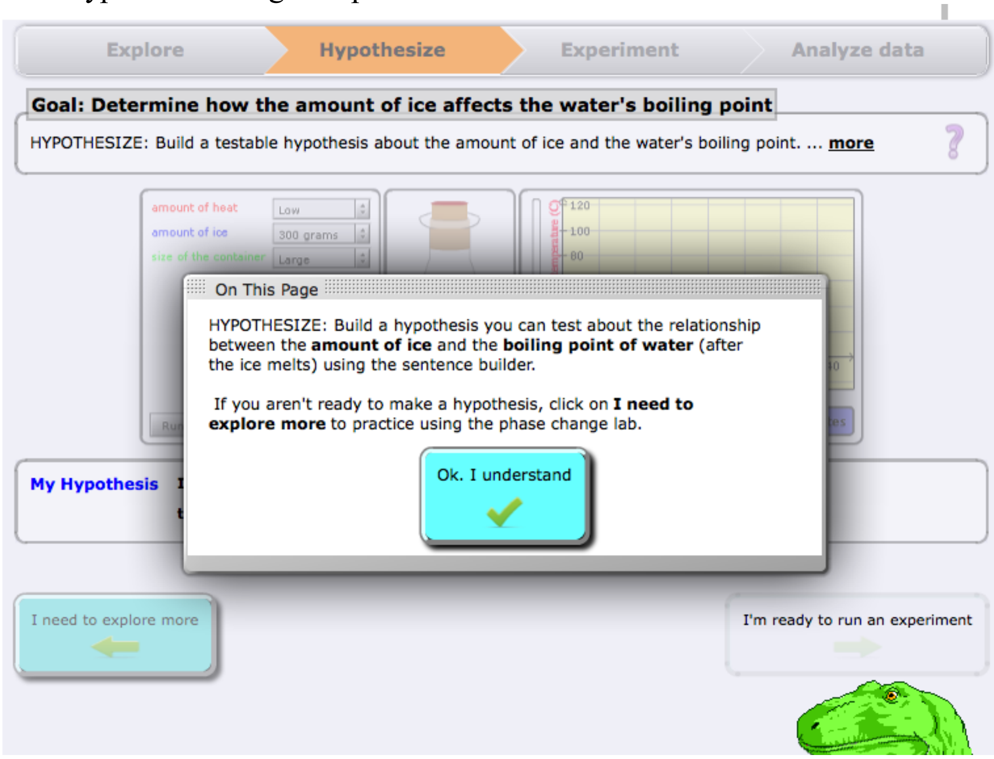
Appendix 5b: Content Pre-Test



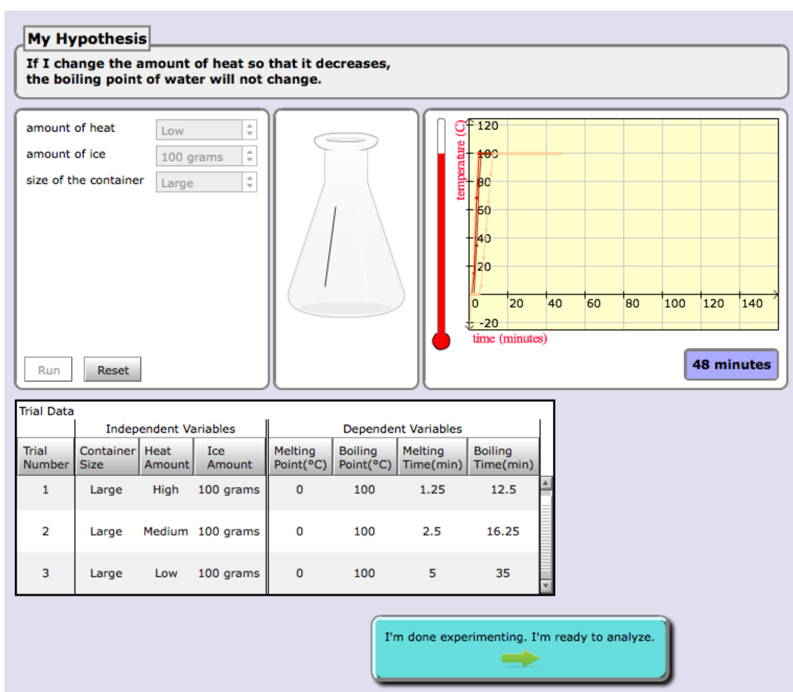
Appendix 6a: Hypothesis Widget Experiment 1



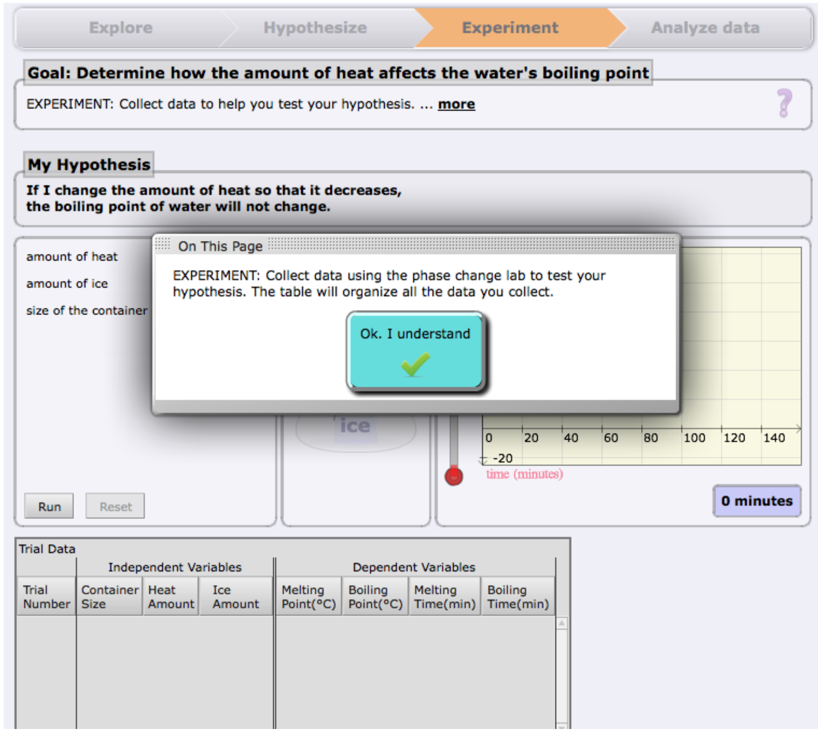
Appendix 6b: Hypothesis Widget Experiment 2



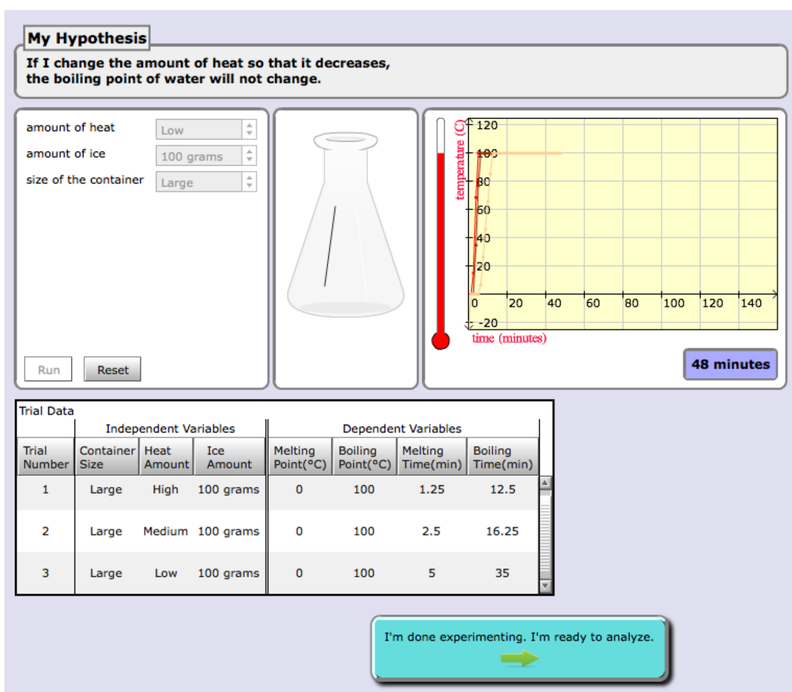
Appendix 6c: Hypothesis Widget



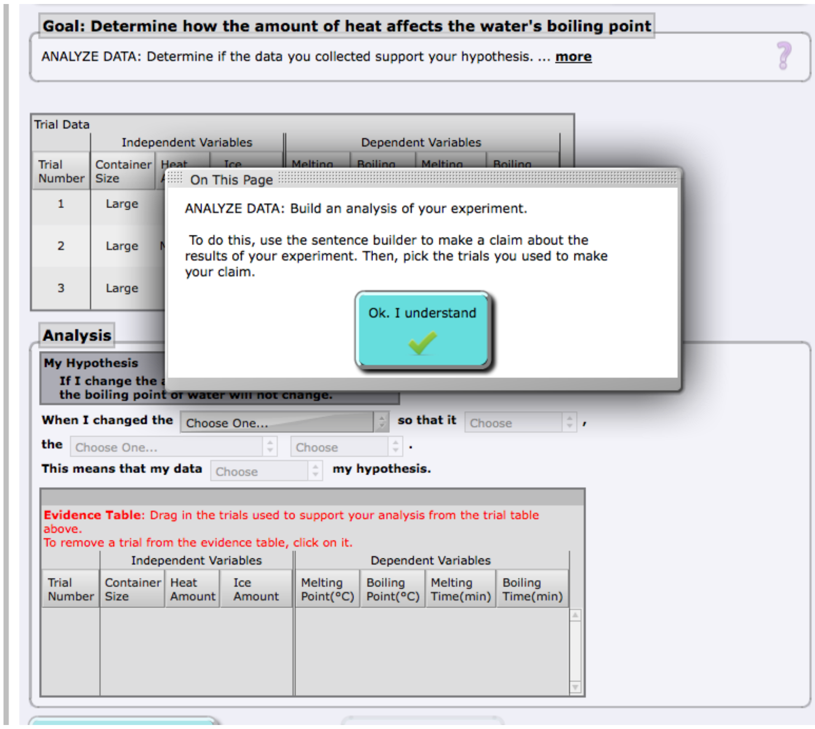
Appendix 7a: Experiment Data Collection



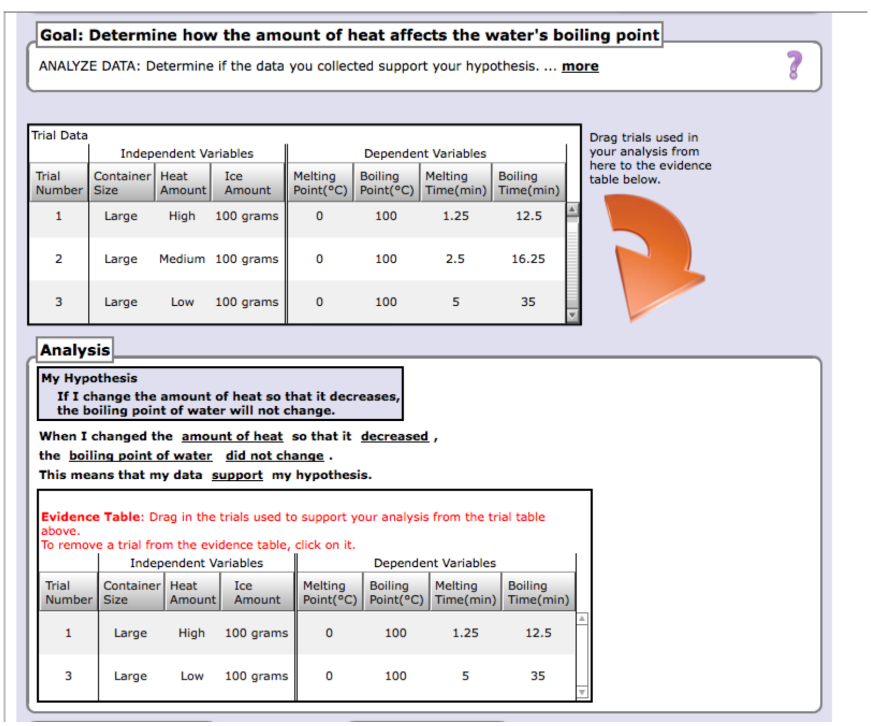
Appendix 7b: Experiment Data Collection



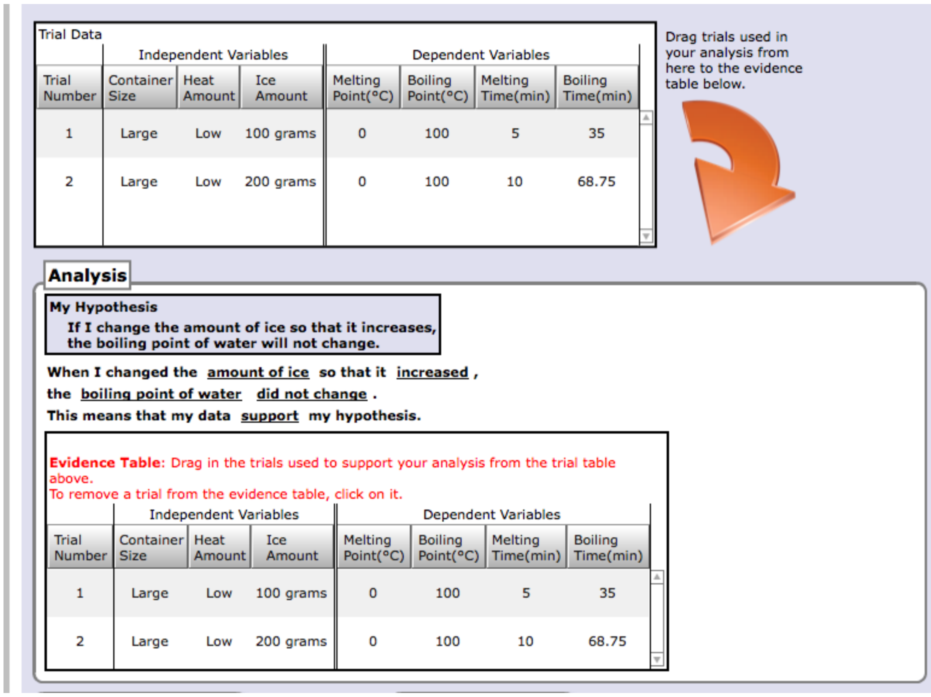
Appendix 8a: Data Interpretation



Appendix 8b: Data Interpretation Experiment 1



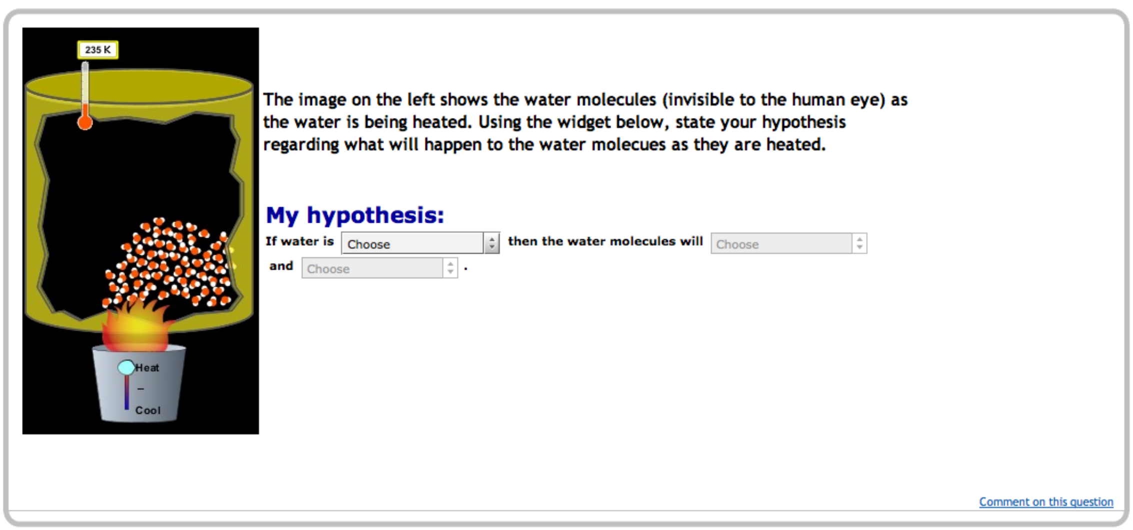
Appendix 8c: Data Interpretation Experiment 2



Independent Variables				Dependent Variables			
Trial Number	Container Size	Heat Amount	Ice Amount	Melting Point(°C)	Boiling Point(°C)	Melting Time(min)	Boiling Time(min)
1	Large	Low	100 grams	0	100	5	35
2	Large	Low	200 grams	0	100	10	68.75

Independent Variables				Dependent Variables			
Trial Number	Container Size	Heat Amount	Ice Amount	Melting Point(°C)	Boiling Point(°C)	Melting Time(min)	Boiling Time(min)
1	Large	Low	100 grams	0	100	5	35
2	Large	Low	200 grams	0	100	10	68.75

Appendix 9a: Microworld Two Hypothesis Widget



Appendix 9b: Microworld Two Hypothesis Widget

The image on the left shows the water molecules (invisible to the human eye) as the water is being heated. Using the widget below, state your hypothesis regarding what will happen to the water molecues as they are heated.

My hypothesis:

If water is heated then the water molecules will gain energy and move faster .

Submit

Comment on this question

Appendix 10: Microworld Two Directions

Please read the directions below carefully.

In the next screen, you will see a simulation that will show you how water behaves when it is in different states of matter.

When you first see the simulation select water; then you can click on "solid", "liquid", or ""gas" to observe the pattern and movement of the molecules in each state of matter.

Next, using the slider below the beaker you can heat up or cool down the container to see how the molecular behavior of water changes as it tansitions between states of matter. **Hold** the slider in the position you want it and observe what happens to the substance at least 15-20 seconds.

Click **"Start Simulation"** below to start a simulation.

When you are done, you may close the simulation, select **"I am done!"** and submit.

Start Simulation!

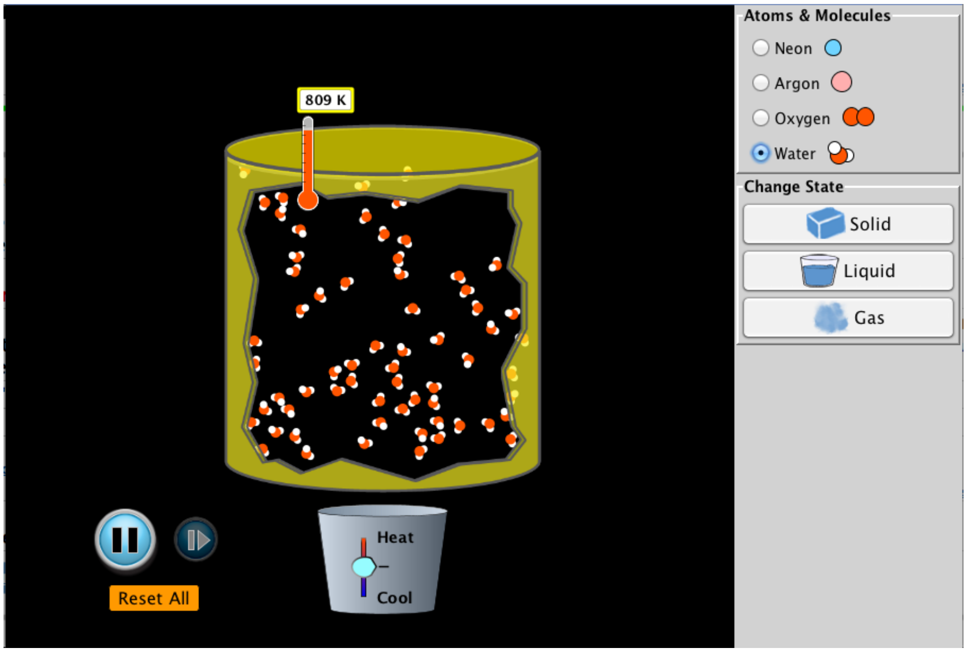
Comment on this question

Select one:

I am done!

Submit Answer

Appendix 11: Microworld Two PHET Simulation



Appendix 12: Microworld Two Data Interpretation