Developing Technology-Based Biology Assessments for Cell Structures and Functions

An Interactive Qualifying Project

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Abstract

While the expectations of the modern education system are expanding, effective methods of assessing student knowledge have become outdated. To fully capture the levels of knowledge of individual students, there is a need for active learning methods and applications in which students can utilize critical thinking and develop inquiry skills for solving scientific problems. Through the use of ASSISTments, a cell biology based Microworld (SimCell) was created in order to target and reinforce scientific observation and standard knowledge of cells and organelle function. In a pilot study of the activity, eleven students were able to apply their initial content knowledge and adapt their skills to solving two basic dynamic problem scenarios related to cell health. The activity successfully assessed: inquiry skills in an experimental context, prior knowledge of cells and organelles, as well as students' abilities to actively learn within an interactive microworld.

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Introduction

Scientific inquiry is no longer the way of only the scientist; it is the way of the average citizen. Modern society expects its citizens to be both knowledgeable and practical in their ability to make decisions and work toward contributing to the whole. “Students must acquire the ability to make up their own minds, to develop freedom of the mind, and to learn to make decisions based upon reason and evidence”(Lawson, 2010).

The American Association for the Advancement of Science described the importance of science in society. “Scientific habits of mind can help people in every walk of life to deal sensibly with problems that often involve evidence, quantitative considerations, logical arguments, and uncertainty” (Lawson, 2010). Science, it continues to explain, should be taught as it is practiced. Students should learn to question nature, actively engage themselves in collecting evidence, and make conclusions based on what they learn. The National Research Council’s *National Science Education Standards* emphasize that science be learned as more than just a list of knowledge, but as a way of thinking (NSES, 1996). According to the Program of International Assessments’ 2006 study, 15 year old students from the United States performed below average in science literacy tests when compared to fifty-seven other countries (Snyder, 2009). With America falling behind, our national organizations are urging teachers to help student achieve in science so they may become creative and critical thinkers (Lawson, 2010).

The first step towards overcoming this educational lag is to assess students and identify common misconceptions in order to develop the modern methods required for helping them succeed in science. As explained in *Knowing What Students Know(NRC, 2001),* the preexisting foundations of learning and assessment of knowledge may be outdated. They are no longer sufficient to support the changes in society’s expectations of education. Over the years, the amount of

information that is expected to be learned by students has increased. Science in particular is subject to amendment as new evidence replaces or enhances existing theories. Teaching, however, has not advanced at the same pace. In today's classrooms, most time is spent reviewing factual information (Lord, 1998). In this dated approach, students are expected to memorize and recite what is presented in their textbooks. This rote memorization may earn good grades on rote-knowledge tests, but it does not provide the students with the foundation expected from their grade level, nor does it prepare them to be citizens in a voting democracy (Lord, 1998). Studies, as described in Knowing What Students Know(NRC, 2001), have shown that students can solve a problem that they have already "studied," but they lack the critical thinking skills of applying the same knowledge to solving new, *similar* problems. To fully grasp the complexities of scientific subjects, students must be able to learn through application. "Students learn best when actively engaged in learning" (NRC, 2001).

ASSISTments

ASSISTments is a computer-based program developed by Neil Heffernan for assessing and assisting students in math (www.ASSISTment.org). Dr. Janice Gobert is currently directing a team at Worcester Polytechnic Institute in the development of a science ASSISTments program. The project includes a sequence of virtual scientific microworlds designed for testing both inquiry and content knowledge while engaging students to interact with this learning environment. The microworlds are developed in coordination with the curriculum laid out by the Massachusetts Education and Learning Strand ("Science and Technology/Engineering," 2001). The program is designed to simultaneously test content knowledge and inquiry skills as well as tutor students on these. The microworlds engage students to think critically and apply their scientific skills in making hypotheses, designing and experimenting, interpreting data, and communicating results, as per the NSES (1996).

Background

Misconceptions

The study of cellular biology is of particular interest because it is fraught with misconceptions (Berthelsen, 1999). Most students begin learning in-depth about the cell in middle school. The knowledge that they obtain at this level of education, whether correct or incorrect, usually persists throughout their secondary and college education. The source of many of these misconceptions comes from the fact that many students have difficulty comprehending ideas at the microscopic level. Research suggests that students have difficulty understanding the relative sizes of cells, proteins, atoms, and molecules. This misunderstanding prevents them from making necessary connections between the structures and functions of cells. For a more comprehensive understanding, they need to grasp the concept of hierarchical organization of these microscopic entities (Berthelsen, 1999).

Furthermore, many students think of organisms in terms of containing cells rather than being composed of cells. To address such a misconception, there is a need for students to explore living things from the familiar macroscopic level and to be gradually introduced to the microscopic level of organs, tissues, and cells. This would also help students visualize the cell in a three dimensional view and help them realize that cells are not planar entities, but rather complex units that make up living organisms ("Misconceptions in Science," 2005).

One of the most difficult concepts for students to grasp is that the cell is made up of a dynamic system of organelles that work simultaneously and interdependently to accomplish the functions required for cell life (Berthelsen, 1999). When students learn the organelles, they are presented with a textbook definition of each name followed by each function. They are not led to

understand the big picture and how it all comes together. Organelles have specific functions, but they are interdependent. One organelle cannot function on its own; cells interact to work in order to keep the cell alive. Oftentimes, students believe that the nucleus controls every action or that each organelle acts independently. According to Flores, Tovar, and Gallegos (2003) these difficulties can be overcome if students experiment and interact with a continuous and dynamic cellular simulation (Flores, Tovar, & Gallegos, 2003).

Massachusetts Education and MCAS Learning Strands

The Massachusetts State Frameworks have presented a Science and Technology/Engineering curriculum that includes Life Sciences (Biology) as one of the four key topics to be covered by public schools. Using these guidelines, it is expected that students at the middle school level (grades 6-8) can observe, describe, apply, and comprehend the relationships involved in the structures and functions of living things.

In grades 6-8, students are first introduced to the idea of viewing the organic world at a microscopic level. They are presented with the underlying structure of organisms, and encouraged to focus on the cell as the basic unit of life. Two of the main subjects that are covered in cell biology include cellular necessities/functions (i.e., energy storage and waste removal required by all organisms) and cellular structure (i.e., the differences between organisms, such as plants and animals, as a result of the different mechanisms carried out by the structurally different cells). It is expected that by the time the use this unit of cell biology, students will have working knowledge of the organelles and an understanding of how structure gives rise to function at the cellular level. ("Science and Technology/Engineering," 2001)

Goals

The ideal learning environment for cell processes is not one which isolates concepts, but rather one which uses simulations, experiments, and interactive/hands-on activities to enhance the learning processes and students' organization of knowledge so that their knowledge can be applied in flexible ways..

In an effort to address student misconceptions and assess students' learning of cell biology at the middle school level as laid out by the MA frameworks, an interactive, computer-based cell, a microworld dubbed SimCell, was designed by this IQP team in conjunction with Dr. Janice Gobert and one of her graduate students, Matt Bachmann. The goal of SimCell is to provide an engaging environment in which middle school student are encouraged to practice inquiry and experimentation skills within the context of an assessment based exercise.

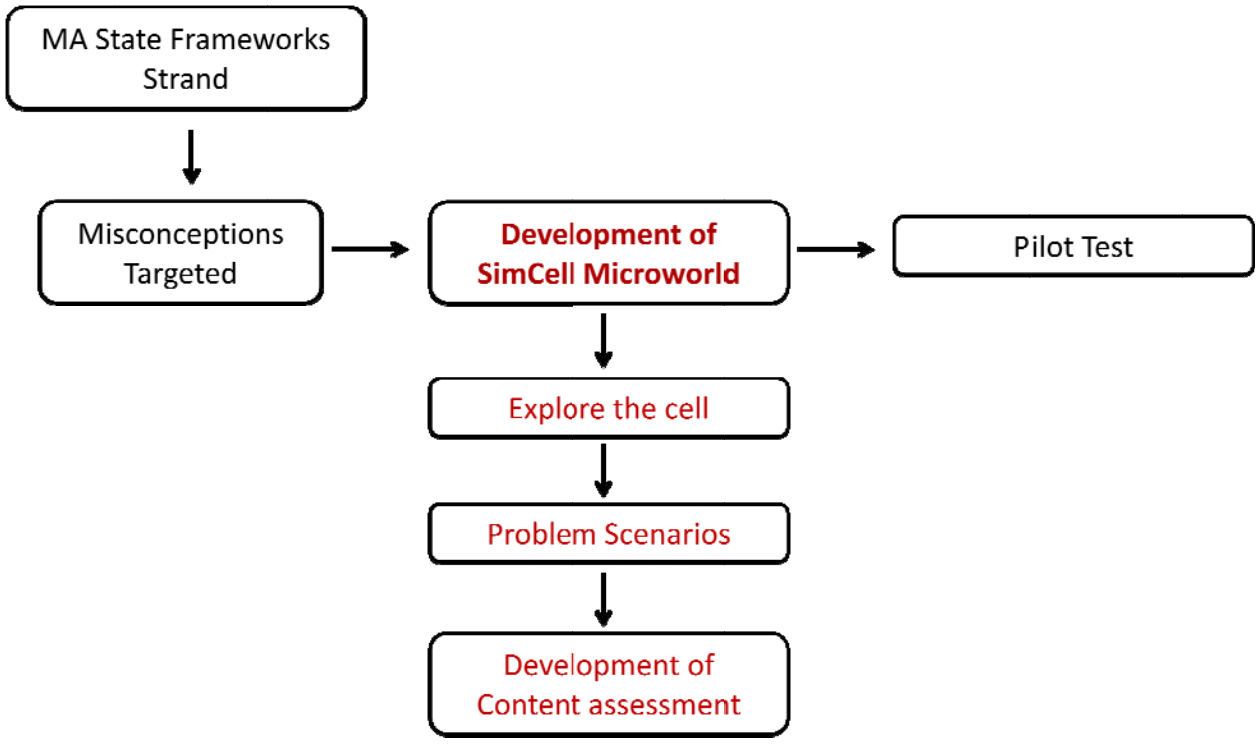


Figure 1: The Process of Implementing the SimCell

Methods

Participants

This study used 11 participants from an after school program in Central Massachusetts. There were 9 males and 2 females, ranging from 13 to 15 years old and between grades 7 to 9.

Data Collection Procedure

Students were individually tested on a computer in a computer lab at a private university in Central Massachusetts during a two hour period. After registering into the ASSISTments site, they performed the Inquiry Pre Test (designed by the Science Assistments team), which served to gauge their basic skills relevant to the scientific process. Students then completed a second pretest to assess content knowledge, designed as part of this IQP, to determine their general understanding of cell biology. This section contained targeted questions on organelle function.

After the completion of these two pretests, they were introduced to the Sim Cell Microworld in which students could explore the cell and microworld interface on their own and develop further their understanding of the relationships between organelles and various indices of cell health: water, energy, life, waste, and protein. The students were then asked to complete two microworlds: Energy and Water/Waste. Once the microworld problem was introduced, students were asked to form a hypothesis and identify variables (organelles) to test in the experiment. Each microworld allowed students to experiment within them – working with variables and recording changes in the various gauges in order to answer their hypothesis. After the completion of the experiment, students answered microworld assessment questions that focused on their interaction with the microworld.

Finally, students completed a post test. This was a repeat of the Content Knowledge pre test at the start of the period to gauge if their knowledge had differed any through the microworld.

Materials

The following section describes the pretest/posttest as well as the SimCell microworld. The ASSISTment can be found at www.ASSISTment.org as well as in Appendices 1-10.

Pretests

Inquiry Pretest

Objective:

The inquiry pretest tests the students' background knowledge on scientific inquiry skills, namely: hypothesizing, designing and conducting experiments (including controlling for variables), interpreting data, and communicating conclusions about their results. This test was developed by the Science Assistments team and was implemented once again after the completion of the microworld activities. These data are not analyzed as a part of this IQP. The inquiry test can be seen in Appendices 1-9?

Content Knowledge Pre- and Post-test

Objective

The content knowledge tests were designed to gain an understanding on students' knowledge of specific organelles, namely targeted ones discussed in the microworld. In addition, this would also assess students on any misconceptions in regards to cell function and whether or not the microworld changed their understanding of organelle function.

Content Pretest

The content knowledge pretest consisted of 7 multiple choice questions and 1 open response question on cell biology and focused on assessing several misconceptions that middle school students often have, as identified in our earlier review of the literature. Out of these questions,

five of them were targeted in the Microworlds designed by our IQP team, in conjunction with Matt Bachmann and Dr. Gobert.

Content Pretest 1 (Main Problem, Appendix 10a)

Question one was an untargeted question that asked students to identify the smallest unit that could perform all functions of life.

Content Pretest 2 (165674, Appendix 10b)

The second question focused on the student's skills at identifying a primary feature of cells – a structure that surrounds every cell.

Content Pretest 3 (165675, Appendix 10c)

Question three is a targeted question from student misconceptions that asked them to identify organelles involved in protein production.

Content Pretest 4 (165676, Appendix 10d)

Pretest question 4 asked students to identify the two types of Endoplasmic Reticulum: "The rough ER differs from the smooth ER because _____" and students were asked to explain their reasoning.

Content Pretest 5 (165677, Appendix 10eX)

Question five was an untargeted question in the microworlds which focused on cell generalizations and asks students to identify a key feature of animal cells from a set of possible answers.

Content Pretest 6 (165678, Appendix 10f)

Targeted question six was an open response that asked students to identify which cell was nicknamed the “powerhouse” and why they believed it was given this name.

Content Pretest 7 (165679, Appendix 10g)

Question 7 is a targeted question in the second Microworld. This question asks for the role a vacuole plays in maintaining cell health.

Content Pretest 8 (165680, Appendix 10hX)

Pretest question 8 focuses on the difference between lysosomes and vacuoles and is a targeted question addressed in the second Microworld.

Microworld Design: SimCell (Appendices 11-17)

Design

SimCell was based off of several different animal cell types as well as information presented in middle school level biology text books. The main interface is an animal cell, which is depicted by an inner and outer layer of circles representing the phospholipid bilayer. An organelle bank is included on the right side of the cell. The organelles in the bank include: the endoplasmic reticulum, the nucleus, the golgi body, the lysosome, the mitochondrion, the ribosomes, the nucleolus, and the vacuole.

Below the organelle bank are five gauges, which represent life, energy, protein, water, and waste levels. Organelle placement within the cell changes the gauge levels. All the gauges, except for waste, begin as black bars containing nothing. The waste gauge begins as a full red bar. The colors in the gauges are indicators of the cell’s health, which is dependent on how much energy,

protein, water or waste is present in the cell. The waste begins as red, which is an undesirable color, as waste is not wanted in the cell. When organelles are added, the initial color of the appropriate gauge changes as well as its level, based upon which and how many organelles are added. Gradually the bar changes from red to yellow to green in varying degrees depending upon the number of organelles required to make the cell healthy. The addition of mitochondria to the cell increases the energy level. The endoplasmic reticulum, golgi bodies, ribosomes, and the nucleus, all increase or decrease protein which is reflected by the protein gauge. The addition of lysosomes and vacuoles decreases the amount of waste present, but only the vacuoles cause an increase in water. The life gauge reflects the overall health of the cell. The life bar is linked to all of the other gauges and is also directly affected by the addition or removal of the nucleus and nucleolus, due to their importance in animal cells.

Due to the nature of cell biology and the complex interactions of living systems, a system dynamics model could be used to represent the interactions of the organelles comprising an animal cell. However, we found that creating a system dynamics model to represent an example animal cell was impractical. The underlying imbedded values used to represent the relationships between the organelles and the gauges were determined based on simple animal cell models, average numbers of assorted cell types to account for variability, and the relative magnitudes of how many of each type of organelle was present in relation to each other. More specifically, to have a completely healthy cell in SimCell, the numbers of each organelle required are as follows: 1 endoplasmic reticulum, 1 nucleus, 6 lysosomes, 3 golgi bodies, 8 mitochondria, 10 ribosomes, 1 nucleolus, and 4 vacuoles. Once the limit has been reached, any amount higher of any organelle causes a decrease in whichever gauge level the organelle is related to.

Explore (Appendix 11)

The purpose of the Explore phase is for students to become familiar with the interface of SimCell. There are eight different organelles each interrelated to one or more of the five gauges. There are two tasks proceeding it which are presented to the student and require that the student interact with the microworld and understand the basic underlying mechanisms of the organelles in regard to cell health.

Exploring the microworld allows students to interact with the interface and learn about the relationships between the organelles and the gauges. Students are presented with an animal cell void of any contents, an organelle bank, and a set of five gauges. The student is asked to explore and learn how the tools work. Depending upon which organelle is placed in the cell, the gauges will reflect that change.

The student has the option to click a reset button, which empties the cell of all organelles and sets the cell back to its original condition. The student is permitted to experiment for an indeterminate amount of time. Once finished, he/she must answer an open response question. The student is asked to "describe to a friend how the different organelles affect the cell". This prompt is based on literature from cognitive psychology on the beneficial effects of providing explanations on learning. After the student's response is submitted, the student proceeds to the next section.

Microworld Problem Scenarios

Objective

The main goal of the problem scenarios is to test for each student's prior knowledge of the cell, as well as his or her skills at applying that knowledge to analyze the given situation by

hypothesizing about what is wrong with the cell, and controlling for variables to test his or her hypotheses and, finally drawing conclusions based on their results.

Activity – Problem Scenario 1 (Appendix 12-15)

The student is presented with an image of a similar looking interface as was presented in the explore mode (cell membrane, organelle bank, gauges), however, in this case the student cannot interact with the cell. This cell has most of the organelles already present within the cell membrane and the gauges reflect the health of the cell based on the amount of organelles present. The cell in not fully healthy and does not have all the organelles present to make the cell as healthy as possible. The main indicator of what is wrong with this cell is the lack of energy.

The student must answer an open response question regarding the state of the cell: “What is your hypothesis about what is wrong with this cell? How can you make this cell healthy?” There are at least a few of every organelle type present to prevent the student from guessing through the process of elimination what organelle might be missing from the cell. This exercise is useful for a few reasons. In terms of content knowledge, it assesses whether the student has prior knowledge of what provides the cell with energy; and in terms of inquiry skills, it assesses how well the student can generate a hypothesis, design and conduct an experiment, and analyze data. Once the student performs these tasks, another open response question appears, namely: “Why do you think this? Explain your reasoning below.” The student is asked to provide a rationale for his or her analysis of the cell. Again, this item measures whether the student has prior knowledge of the cell (content knowledge), and also measures his/her reasoning with data.

After the student submits his or her answer, the next section appears. The student is required to build a hypothesis using the hypothesis widget and construct a hypothesis such as, “I think the number of <organelle> needs to <increase/decrease> in order for <gauge level> to

<increase/decrease>" (organelle, increase/decrease and gauge level are drop down menus). The student clicks "Add statement" and the statement is added to the list of hypotheses to support hi/her in monitoring their inquiry. A new window appears and the student has a choice to click on the "I need to explore more" button or the "Let me add more hypotheses" button. If the student chooses to add another hypothesis, the page remains on the hypothesis builder. The student can add another hypothesis, decide to return to the cell interface and explore more, or decided to run his or her experiment. If the student chooses to explore more, whether after building a hypothesis or after choosing to add another hypothesis, the student now has the ability to explore the cell with the specific hypothesis in mind or try different new ideas. The explore interface has a cell the same as the original image presented lacking enough mitochondrion. The student can add or remove as many organelles as he or she desires and/or click on the reset button. The reset button returns the cell to its original conditions.

After making several hypotheses, the student is required to interpret his or her data, which are displayed in a data table widget (designed by the Science Assistments team). The data interpretation statement reads "when I changed the number of <organelle> so that it <increased/decreased> the <gauge> <increased/decreased>." After forming a statement, the student can add the statement by clicking on the add statement button. Once the student is ready to run an experiment the interface changes slightly.

At this point in the activity, the interface has several new buttons: Reset, Record, Show Table, I'm done experimenting. I'm ready to analyze. The student can record the cell's status at any point during their experimental trials. Information recorded in the table includes the number of each organelle present and the percentage of each gauge, which is displayed in a table. The organelles in the table are labeled as the independent variables and the gauges are labeled as

dependent variables. The goal is for the student to record the results of their experimentation (adding/taking away specific organelles) in order to test his or her hypotheses. The data table allows researchers to check whether the student has used the control for variables strategy in their experimenting (control for variables is an experimental strategy in which the target variable is changed and all other variables are kept constant; this is necessary in order to collect unconfounded data). Check boxes for "Supporting Data," are aligned with each recorded status in the table which the student can click to identify whether the recorded status supports his or her hypothesis(es).

Once the student thinks that there is enough data to support their hypothesis, he or she clicks on "I'm done experimenting, I'm ready to analyze" and another Data Interpretation widget is available. It is the same as the one used in the hypothesis phase. There are three options the student can chose after adding a data interpretation statement, "Go back, I need more data", "I'm done. Let's do another hypothesis", and "I'm all done." The first option is for conducting further tests to record and test further. The second option is for testing a different hypothesis. If the student made more than one hypothesis initially, he or she can return to select a different one and repeat the same procedure of changing different amounts of organelles and recording the cell's status at points during the experimenting.

Embedded Assessment Questions for Problem Scenario 1 (159817, Appendix 15)

After completing data analysis, there are several embedded questions for the student to answer. The first of which is **"What gauge or gauges indicted that the cell was not healthy? Check all that apply."** The options for answers are life, energy, protein, water, and waste. This question is to assess if the student can identify the connection between why the cell was not healthy and

which gauge provides that information. For this specific case, the life and energy gauges were the correct responses. The cell required energy, which was indicated by the energy gauge; the life gauge also indicated insufficient levels to be completely healthy.

The next question is **"What caused this problem in the cell?"** The options here are not enough nuclei, not enough mitochondrion, too many ribosomes, and too many vacuoles. If the student previously was unaware of what provided the cell with energy, the activity should have enabled the student to discern that the mitochondria numbers were too low in the cell and that this is shown in the energy gauge. This question is assessing if the student made the connection between energy gauge and mitochondria.

The next question targets the student's skills at following through with his or her initial diagnosis/hypothesis of the problem and attempt to test it. The next question is as follows: **Which organelle or organelles did you add or remove to make the cell healthy?** The answer choices are ribosomes, golgi, nucleoli, mitochondrion, and lysosomes. If correct, the student would add mitochondrion to make the cell healthy, and therefore would choose this as his or her answer. After completing these embedded questions, the student proceeds to Problem Scenario 2.

Activity – Problem Scenario 2 (85470, Appendix 16-17)

Problem Scenario 2 has the same goals and activity progression as Problem Scenario 1, but is slightly more complicated in terms of the number of variables which need to be accounted for due to an increase from one organelle being targeted in the first scenario to two organelles being targeted in this second scenario. The beginning of the activity is similar to Problem Scenario 1, the student is presented with an image of the interface in the explore mode (cell membrane, organelle bank, gauges), as previously described, students cannot interact with the cell. The cell is not fully healthy and has high levels of waste and low levels of water as well as an overall low

life level. In order to make the cell healthy, both lysosomes and vacuoles need to be added. Both organelles assist in waste removal but only vacuoles store water necessary for the cell.

The student proceeds through this scenario in the same inquiry phases as Problem Scenario 1. The entire progression through explore, hypothesis, data interpretation is the same format. The only differences here are that there are two different independent variables to control for, therefore, more steps need to be taken in each activity section to account for multiple hypotheses.

Embedded Assessment Questions for Problem Scenario 2 (165248/165257, Appendix 17)

After completing data analysis, same format as Problem Scenario 1, there are several embedded questions for the student to answer. The first of which is **"What gauge or gauges indicted that the cell was not healthy? Check all that apply."** The options are life, energy, protein, water, and waste. This question is to test to see if the student could identify the connection between why the cell was not healthy and which gauge provides that information. The life gauge obviously demonstrates an unhealthy cell due to low levels, as does the water gauge because there are insufficient water levels within the cell. The more complicated interpretation would be the waste gauge. Waste in a cell causes harm, so high levels of waste would indicate the cell health is not optimal.

The next question is **"Which organelle or organelles did you add or remove to make the cell healthy?"** The choices are endoplasmic reticulum, vacuoles, golgi, lysosomes, and mitochondrion. There are two answers: vacuoles and lysosomes. Both of these organelles are required for waste removal and the vacuole is necessary for water storage. This question can demonstrate a student's partial understanding of the cell state of health. If only lysosome is selected, then the student may be aware that the lysosome is related to the waste, but if both are

selected, the student knows that both have an effect on waste but not necessarily the effect of the vacuole on the water level.

The next question asks the student to differentiate which organelle targeted waste but not water. **"Which organelle helped remove the waste but did not increase the amount of water being stored by this cell"**. The responses to choose from are lysosome, vacuole, endoplasmic reticulum. The first two answers would both be correct for the first part of the question but the differentiating factor is the removal of water. The correct answer to this question is the lysosome as the function of the lysosme is waste removal and not the storage of water (which would be the function of the vacuole). The third and forth answers,endoplasmic reticulum and golgi, are related to protein levels, which if selected would indicate possible guessing or no understanding of the activity.

The next question requires the student to again make the same distinction, except this time the organelle, which also increases water storage, should be identified. **Which organelle helped remove waste and increases the amount of water being stored in this cell?"** The answer choices are identical to the previous problem, however the correct answer in this case is the vacuole. These two questions, just described, are targeting in particular the student's skills in Problem Scenario 2 to distinguish the different functions between the vacuole and lysosome.

Coding of Data

Student data was scored to obtain information on their prior content knowledge, their interaction and application of content and inquiry skills within the microworlds, and their content knowledge gained as a result of engaging in inquiry within the microworlds. The multiple choice questions of both the pre/post content tests and those embedded within the microworld were

automatically scored by the ASSISTments infrastructure as either correct or incorrect (receiving 1 or 0 points, respectively).

The open response questions were hand-coded. They were scored based on depth and richness of the explanation given by each of the students. Depending on the question, the scores ranged from 0-4 points. The table below shows how the scoring of each question was broken down.

Table 1: Specific coding of student open responses

Assessment Componenet	Open Response Question (points)	ASSISTment #	Score
Bio pre/post	• Powerhouse of the cell = mitochondrion (1) • Powerhouse because it produces energy (1)	85466	0-2
Microworld Scenario 1	• Hypothesis: unhealthy because too few mitochondria (1) = not enough energy(1) • Make cell healthy: add more mitochondria(1)	159815	0-2 0-1
Microworld Scenario 1	• Hypothesis based on: energy gauge is low (1) • Reasoning: add more mitochondria (1) energy bar increases (1).	159816	0-1 0-2
Microworld Scenario 2	• Hypothesis: unhealthy because too few vacuoles (1) and lysosomes (1)= not enough water (1) too much waste(1) • Make cell healthy: add vacuoles (1) and lysosomes (1)	161663	0-4 0-2
Microworld Scenario 2	• Hypothesis based on: water gauge is low (1) waste gauge is high (1) • Reasoning: add more vacuoles (1) water bar increases waste decreases (1) add more lysosomes (1) waste bar decreases (1)	161664	0-2 0-4

Results

Because there were only 11 students, quantitative data analyses were not possible due to low subject sample. Thus, our data are analyzed in a case study manner for each student by examining the independent pre-test content scores, embedded assessment questions, log files of each student's interactions in the microworld for each problem scenario, and the post-test scores for content.

Table 2: Summary of Student Scores on Pre/Post Biology Content Tests and Microworld Activity

Student Info		**Biology Content Scores**		**Microworld**
Student	*ID #*	*Pre test*	*Post test*	*Embedded Questions*
1	72140	56%	78%	64%
2	84412	11%	33%	21%
3	84415	56%	67%	42%
4	86988	22%	33%	32%
5	86989	22%	22%	35%
6	86992	11%	22%	21%
7	86993	22%	78%	43%
8	86996	44%	56%	57%
9	86997	33%	22%	32%
10	86998	44%	11%	7%
11	87000	67%	44%	64%

Student Analysis

Student One

Background Information

Student one is a 13 year old male in eighth grade. He indicated that is favorite classes are Spanish, Art, Math and Sports. His attitude toward science is that it is an easy subject that he enjoys learning at all times. He said his general grades for all subjects were in the A range as well as his science grades.

Biology Pre Test

The student scored an overall 56% on the biology content pretest. The first question (main problem) is untargeted by our microworld and asks the student a general question about the cell, which the student answered correctly. Question two (161648) asks about cell structure and also not targeted by this microworld. The student correctly answered this as well. Because this student answered the first two general questions correctly, he may have prior biology content knowledge. Question three (161651) was targeted by the microworld asking about specific organelle function, which he answered incorrectly. This question is the first asking about details of organelle function, protein production and transportation, which requires a deeper understanding of organelles rather than a general knowledge. Question four (161652) also asks about a difference in organelle structure regarding the rough and smooth endoplasmic reticulum, which was answered correctly. This, in conjunction with the other structural and functional questions also suggests this student has prior biology content knowledge. Question five (161654) was not targeted by the microworld and not answered correctly, however, it still could suggest that the student had prior knowledge; the question asked about generalized knowledge of an animal cell.

Question 6 (161655) is the only open response question, indirectly targeted by the microworld. He answered incorrectly. The question is in regard to the mitochondrion of the cell, which classically is defined in textbooks as the 'powerhouse', but the student's answer suggested that he understood the nucleus to be in control of the cell, even if it did not supply the cell with power. Question seven (161656) was answered correctly and is specifically targeted by the microworld regarding vacuole function. Question eight (163933) also is directed toward organelle function, in this case the lysosome and vacuole, which the student also answered correctly marking the distinction between both of the organelles as well as their similarities. Based upon his answers, the results suggest that this student has a basic understanding of organelles and most of their functions.

Problem Scenario 1

In question 159815, the student clearly states that the cell is lacking energy and requires more mitochondria to provide that energy demonstrating ability to analyze the cell based upon the gauges as well as content knowledge of the function of mitochondrion. In question 159816, his reasoning as to his hypothesis is that the more mitochondria, the more energy the cell will have. His statement is correct but neglects to mention that the gauge indicates low energy.

In Problem scenario 1 (159817) the student's hypotheses very explicitly targeted the cell's lack of mitochondrion. He stated in the hypothesis widget that "as mitochondria increased, the energy increased". To test this hypothesis, he only recorded two cell statuses, which did show one change in variables; he increased mitochondria to eight, to obtain a perfectly healthy cell. He could have tested his hypothesis on the cell without recording any of his progressive changes or he might already have the content knowledge to make the assessment based upon the gauges to

assume the cell requires more mitochondrion to obtain the correct amount of energy and added them until the cell was completely healthy.

His analysis indicated the same in the data widget; mitochondria increase caused an energy increase. The student's answers and interaction with the cell are indicative of high content knowledge as well as consistency in testing his stated hypotheses. He is methodical and he demonstrates skills at observing, hypothesizing, testing, and analyzing data in an organized manner.

Embedded Question 165245

Through prior knowledge and interaction with the microworld, Student 1 also correctly answered the embedded question, i.e., "that the lack of energy was caused by not having enough mitochondrion in the cell."

Problem Scenario 2

In question 161663 the student makes an educated guess as to what is causing the cell to be unhealthy. His partially correct response "the cell has little water and still has waste in it. By adding more vacuoles to the cell you will increase the water and decrease the amount of waste in the cell is what will make it healthy"" indicates that he understand the adding of water and removal of waste will make the cell healthy. He identified that the cell requires more water and a decrease in waste and that the organelle that does both of those is the vacuole. He did not mention the lysosome but it is obvious that he understood the underlying causes to the unhealthy cell. The vacuole stores water, but the student does realize that the vacuole is important with regard to water as well as waste removal.

In Problem Scenario 2 (161665), Student 1 hypothesizes via the hypothesis widget that "as the vacuoles increase, water increases and that as the vacuole increases, waste decreases". These are

consistent with his original observations, as evidenced by his answer for question 161663. As noted in his log file for this activity, he proceeds to only record two identical cell statuses. He changed the number of vacuoles so the water level was at 100%. He only changed one variable, but did not record his cell as 100% healthy.

Using the data analysis widget he provides three analyses: “as lysosomes decrease, waste decreases”; “as the vacuoles increase, water decreases”; and “as the vacuole increases, water increases”. In his experimentation, as was observed in his log files, he is not using/demonstrating use of the control for variables strategy because he changes multiple organelles at once. He already has prior knowledge about the vacuole (as evidenced in his pre-test), and from his data interpretation and analyses, he seems to know the vacuole is connected to water and that both the vacuole and lysosome are connected to waste. However, he is unable to infer their function in regards to the variables (organelles) he has changed. He seems to be letting prior knowledge interfere with his skills at thinking critically regarding multiple variables.

Embedded Questions 165248 and 165257

Through some prior knowledge and interaction with the microworld, Student 1 correctly answered the multiple choice embedded question regarding the lysosome being added/removed to make the cell healthy based upon the results from the log files. He also correctly answered the second multiple choice question regarding the specific function of the vacuole as increasing water and removing waste in the cell. This could indicate that even though he did not seem to have a very sound method to control for variables or to analyze data, he was still able to correctly identify the function of the organelles. His responses are possibly based on prior content knowledge, interaction with the microworld, or some combination of both. In any case, this

student demonstrates understanding of the specific functions of the targeted organelles and their relationship to overall cell health.

Biology Post Test

The student scored an overall 78% on the biology content posttest, however, every question (main problem, 165674, 165675, 165676, 165677, 165679, 165680) was correctly answered by the student except question 6 (1615678). The same response as the pretest was “the nucleus is the ‘powerhouse’ because it is the control center of the cell”. Based upon his answers, the results suggest that this student had content gains through interaction with the microworld as the targeted questions from the pretest were correctly answered.

Student Two

Background Information

Student two is aged 14 years in the eighth grade. His response specified that math and gym were the classes he enjoyed the most with a neutral interest regarding learning science and found the subject material somewhat easy to learn. He stated his grades were in the B range but his science grades were in the C range.

Biology Pre Test

The student scored an overall 11% on the biology content pretest. The first question (main problem) is untargeted by our microworld and asks the student a general question about the cell, which the student answered correctly. Every other question asking about cell function and/or structure, namely, questions two (161648), three (161651), four (161652), five (161654), question 6 (161655), seven (161656), and eight (163933), were all answered incorrectly. His answers indicated he might not understand the difference between a cell wall and a cell membrane: the cell membrane is present in all cells, but the cell wall only provides protection and structure in plant cells. His data are also consistent with a lack of understanding of organelle

functions, though question six (161655) asks about the 'powerhouse' which he stated was the nucleus because it is the brain of the cell. He does understand that the nucleus plays a very important role and definitely plays a part in controlling the cell, but has incomplete information with regard to that function. Overall, this student's data suggest that he did not have very high level of prior content knowledge.

Problem Scenario 1

In question 159815, the student states that the cell is lacking energy and that there is "not enough waste in your body to help you live." The student observes that the cell requires energy but is misreading the waste gauge and interpreting waste as essential instead of an unnecessary cellular component. In question 159816, his reasoning regarding his hypothesis is that the picture "shows so." He neglects to indicate the energy and wasted gauges, which are providing him with the information to validate his hypothesis.

In Problem scenario 1 (159817) the student's hypotheses using the widget declared that "as the nucleolus decreased, wasted would increase". To test this hypothesis, he only recorded one cell status, which did not show that he changed the number of nucleolus, following through to test his theory but changed the number of vacuoles, lysosomes, nuclei, Golgi, mitochondrion, and ribosomes instead. He did not form any other hypotheses, nor did he record any other states of the cell, as evidenced by the log files . The table shows a decrease in protein, water, cell life, and an increase in waste and energy but his analysis of the table is inconsistent with these data. His two interpretations from the widget are as follows: "as the nucleus becomes one, energy decreases", and "as ribosomes increase, energy increases". Neither of these conclusions matches his original hypothesis, nor are they correct interpretations of the data he collected. The organelles indicated do not perform the function he listed. His initial hypothesis and testing of

hypothesis were not consistent with each other; furthermore, the rest of his actions indicate that he was not performing any kind of control for variables strategy. His data suggest that he has not acquired an understanding of the functions of the organelles or their relation to overall cell health, as evidenced by the answers from his recorded data interpretation log.

Embedded Question 165245

Even though Student 2 haphazardly interacted with the microworld as shown in the log files in which it appears as though recorded seemingly random additions or subtractions of organelles, he correctly answered the multiple choice embedded question about mitochondria causing the problems within the cell. This could indicate that even though all the data regarding this student indicates a lack of scientific method (meaning his lack of methodical progression from observation to hypothesis, to controlling for variables, etc.) and the apparent lack of prior content knowledge, interactions with the microworld might have had a positive impact on his understanding of the mitochondria and its role within the cell.

Problem Scenario 2

In question 161663, the student states that the cell is healthy because “it has enough energy and protein”, the fact that the cell has enough energy and protein is an accurate observation. However, it does not address the question of why is the cell unhealthy. He also does not reference any organelles that might affect those levels. The student’s logged answer to question 161663 does not have any sufficient observations to verify his hypothesis, only a statement of “because it is shown above.” This would indicate the student does not have prior knowledge of the cell and is inexperienced in scientific observation.

In Problem Scenario 2 (161665), Student 1 hypothesizes via the hypothesis widget that “as the endoplasmic reticulum decreases”, water increases and as the vacuole decreases, waste

increases". The student does recognize that water is lacking in the cell, as is noted by his first hypothesis, as well as a reference to waste levels in the second hypothesis. However, he does not record any status of the cell to test his hypotheses or analyze the data. His statements in the data interpretation widget also do not relate to his original hypothesis: "nucleolus becomes one, energy increases" and as the "nucleus becomes one, energy increases". Neither of these statements is accurate. He does not seem to be interacting with the microworld, controlling for variables, or coming to any conclusions as to the general health of the cell. He is either not interacting with the cell at all, due to no cell statuses being logged or is haphazardly trying random variations of organelles; however, which of these is accurate cannot be verified as he did not record any data.

Embedded questions 165248 and 165257

Even though Student 2 haphazardly interacted or did not interact at all with the microworld, he correctly answered the embedded question about lysosomes being added/removed to make the cell healthy. He also correctly answered the multiple choice question regarding the specific function of the vacuole increasing water and removing waste in the cell. This could indicate that even though all the other data regarding this student indicates a lack of scientific method (meaning his lack of methodical progression from observation to hypothesis, to controlling for variables, etc) and prior content knowledge (his answers to the targeted questions in the pretest were almost all incorrect), interaction with the microworld might have had an impact on his understanding of the function of the two organelles functions and tasks specific to them because he answered the embedded questions correctly.

Biology Post Test

The student scored an overall 33% on the biology content posttest. On the main question his response about the cell was correct. On untargeted question 165674, his response was incorrect.

On targeted question 165675, his response was incorrect, which from interaction with the microworld, he should have discovered that the lysosome does not have an impact on protein production or transportation. Question 165676 was incorrectly answered. The next question, 165676, was correctly answered but was not targeted by the microworld. Open response question 165677 was also answered incorrectly. The student's logged answer stated "[the nucleus is the 'powerhouse'] because it is the brain of the cell" which, through his analogy, indicates that he realize the nucleus directs the cell. Question 165678 was multiple choice and targeted by the microworld in terms of the role of the vacuole. The student answered this question, which could be an indicator of content gain. However, the last question, 165679, was also targeted by the microworld and he answered it incorrectly. The overall results from the logged files and answers to all prettest/posttest and embedded questions remain inconclusive with regard to whether this student made content gains. The results suggest that this student would benefit from assistance in terms of scientific method i.e., methodical progression from observation to hypothesis, to controlling for variables, etc.

Student Three

Background Information

Student Three is a male, aged 14 years, and is in eighth grade. His favorite class is math but he enjoys learning science sometimes and finds it somewhat easy to learn. He indicated that his grades were mostly in the B range as well as his science grades.

Biology Pre Test

The student scored an overall 56% on the biology content pretest. The first question (main problem) was answered correctly. Question two (161648) asks about cell structure, which he answered incorrectly, not making the distinction between cell membrane and cell wall. Question three (161651), question 4 (161652), and question five (161654) were content and organelle

function/structure-based questions, which the student answered correctly, suggesting that he has had prior biology content knowledge. Open response question 6 (161655) was answered incorrectly and no actual organelle was stated, only that the 'powerhouse' organelle tells the other organelles what to do. This further suggests possible misunderstanding of the question. Question seven (161656) was answered incorrectly and since the question specifically addresses vacuole function, this suggests that the student may not have complete knowledge of the cell regarding vacuole function. However, he answered question eight (163933) correctly, which makes a fine-grained distinction of the functional differences between lysosomes and vacuoles. Based upon his answers, the results suggest that this student has a basic understanding of organelles and most of their functions.

Problem Scenario 1

In question 159815, the student states that the cell is lacking energy and requires more mitochondria to make the cell healthy, demonstrating skill at analyzing the cell based upon the gauges, as well as content knowledge of the function of mitochondrion. In question 159816, his reasoning for his hypothesis is that "the cell is lacking a larger number of mitochondria". His statement is correct but neglects to mention that the gauge indicates low energy.

In Problem scenario 1 (159817) the student's hypotheses explicitly targeted the cell's lack of mitochondrion. He also made an inference as to the function of the nucleolus. His two hypotheses are as follows: "as mitochondria increase, energy decreases", and "as the nucleolus becomes one, protein increases". This student recorded multiple statuses of the cell to test his hypotheses, as shown by the recorded log files. Specifically, he recorded an initial state of the cell followed by multiple changes in only one independent variable, the mitochondrion. In each recorded trial, he increased the number of mitochondrion by one or slightly more than one. Once

the energy levels were stable with eight mitochondria, he proceeded to increase the number of vacuoles by one only one. He did not test his hypothesis about the nucleolus, but this is unmistakably a perfect example of controlling for variables to test his hypothesis of the effect of mitochondrion on the energy levels of the cell.

He stated in the hypothesis widget that “as mitochondria increased, the energy decreased”. To test this hypothesis, he only recorded two cell statuses, which did not show any change in variables, only the original status of the cell. There are two potential situations: he already had content knowledge or he did not record the cell. If the first situation, he might have made the assessment based upon the gauges showing a lack of energy and therefore required more mitochondrion. If the latter, he could have tested the cell without recording any of his changes. His analysis in the data interpretation widget indicated the same as in the hypothesis widget: “mitochondria increase caused an energy increase”. Even though his responses from the pretest are consistent with prior content knowledge, the log files show he veritably tested his hypothesis through controlling variables and markedly proved he can verify his claims with demonstrative data, which will be further discussed.

In terms of his analyses with the data table, the student had some interesting responses. He had two analyses regarding the mitochondria: “as mitochondria decrease, energy decreases” and “as mitochondria increase, energy increases”. This is interesting because these analyses contradict each other. This student proceeds through the entire exercise with specific ideas in mind, disregards the nucleolus hypothesis early on when he realizes it is not pertinent to the current status of the cell. He also demonstrates excellent skill at controlling for the correct variables, analyzing the recorded values, and communicating his findings, which actually refute his original hypothesis. The interesting part is that he stated a hypothesis, tested it thoroughly, and was

cognizant enough to realize that his original assumption was incorrect; this demonstrates a very good understanding of various inquiry skills.

Embedded question 165245

Through prior knowledge and interaction with the microworld, Student 3 correctly answered the embedded question that the lack of energy was caused by not having enough mitochondrion in the cell.

Problem Scenario 2

In question 161663, Student 3 suggests that more vacuoles will make the cell healthier, “it does not have enough vacuole you can make it healthy by adding more vacuoles.” He does not state what he thinks is wrong with the cell, but seems to understand that the vacuole is important to its overall health. His answer to question 161663 is that the “vacuole store waste”, demonstrating further that he has some prior content knowledge about organelle function.

In Problem Scenario 2 (161665), Student 2 hypothesizes via the hypothesis widget that “as the vacuoles increase, water increases” and that “as the vacuole increases, waste decreases”. These are consistent with his original observations as evidenced by his recorded statements for question 161663. The student records three different scenarios as seen in his log files. The original status of the cell only has two vacuoles which in his first recorded status, he increased only the amount of vacuoles to 5. The next recorded status only had one vacuole, which was the only organelle that was varied. The final status he recorded included an undefined amount of vacuoles. He is demonstrating the control for variables by only changing one independent variable at a time, as seen in the logged files. In this case, his focus on just the vacuole seems to be inhibiting any possible ideas regarding any other organelles that might have an impact upon cell health.

Using the data analysis widget he provides three analyses: “as the vacuole increases, water increases”, “as the vacuoles increase, waste decreases”, and finally, “as vacuoles increase, waste increases”. He understands that the vacuole is important in order to have enough water in the cell. One important point though is that he does not check any other organelles that might have an impact upon the amount of waste. According to the rules governing the microworld, if the amount of vacuoles is increased past the desirable amount, the waste does begin to increase, however, if the desirable amount is recorded but there is an insufficient amount of lysosomes present within the cell, the waste will never be at the optimum level of 0%. He seems to be letting prior knowledge interfere with his skills at thinking critical regarding multiple variables.

Embedded questions 165248 and 165257

Student 3 incorrectly answers the first embedded question, which requires the student to make the distinction between the functions of the vacuole and lysosome. His response is the vacuole, which was the only organelle he seemed to be testing within the micrworld, as evidenced by his log files. His answer to the second question was correct because that one specifically targets the vacuoles function. He interacted with the microworld but due to sufficient lack of evidence within his responses to the embedded questions or log files in regards to testing the lysosome, it seems his prior content knowledge interfered with his ability to realize there was more than one variable to be accounted for within this specific exercise as he only tested for the vacuole.

Biology Post Test

The student scored an overall 67% according to the scoring scheme on the biology content posttest. Question 165675 was not targeted by the microworld and was not answered correctly, however the main problem, and questions 165674, 165676, 165677, 165679, 165680 were all correctly answered. Questions 165678, 165679 regarding vacuole and lysosome function, were previously answered incorrectly in the pretest but due to his correct responses on these items on

the post-test, it appears that he gained content knowledge from the microworld interactions. Question 6 (1615678) had the same response as the pretest, i.e., “the nucleus is the ‘powerhouse’ because it ‘tells the others what to do.” Based upon his answers, the results suggest that this student had content gains through interactions with the microworld, as the targeted questions from the pretest were correctly answered on the post-test.

Student Four

Background Information

Student 4 is a 15 year old male in the ninth grade. He finds his favorite class is history yet enjoys learning science at all times. He finds science classes usually easy and reported his grades as B for all subjects, including science.

Content Knowledge Pretest Results

This student scored 22% on his content knowledge pretest. Out of these questions, student four correctly answered questions one (main problem) and five (16154) – untargeted questions that focus on cells and their general function. However, question two (161648) is another untargeted question that the student did not answer correctly. Multiple choice questions three (161651), four (161652), seven (161656), and eight (163933) were all answered incorrectly. These are targeted questions concerning basic definitions of organelles and function. Question six (161655), the ‘powerhouse’ open response question, was incorrectly answered. The student did not specify an organelle, but rather defined a cell to refer to “powerhouse”. In this case, the student appears to have misread the question rather than providing the incorrect organelle. Since he incorrectly answered all targeted questions and a third untargeted question, this suggests that the student probably has minimal to no prior content knowledge.

Problem Scenario 1:

In question 159815, the student suggests adding an endoplasmic reticulum and two more mitochondria in order to increase the energy. He states that this is necessary in question 159816 because during the exploration phase, the student saw that this produced energy (via increased the gauge markers).

In Problem scenario 1 (159817), the student's hypotheses in the widget declared that "as the vacuoles increase, waste decreases" and "as mitochondria increase, energy increases". Only the latter of his hypotheses tests his original observation as he indicates an increase in mitochondria is necessary. His initial observation indicated that the endoplasmic reticulum was required for energy increase but he limited his hypotheses to only the vacuole and mitochondrion.

To test his hypotheses, he recorded four different cell statuses. The first status recorded in the log files show that no organelles were added or removed. The next two recorded statuses indicate an increase of mitochondria from two to eight in total. The final two statuses show that the number of mitochondria was decreased from the previous recorded statuses to seven total mitochondria. He was consistent in that he only changed one variable at a time, as seen in his log files, suggesting some ability in controlling for variables. He did test his other hypotheses as there was no evidence collected in his log files regarding any change in amount of vacuoles.

In terms of data table analysis, the student had some interesting responses. He had two analyses regarding the mitochondria: "as mitochondria decrease, energy decreases" and "as mitochondria increase, energy increases". Both of these are accurate in regards to the logged data interpretation table. The table shows that as the mitochondria increases from two to eight, there is an increase in energy as well as when the mitochnodria decrease from eight mitochondria to seven, there is indeed a decrease in energy. Thus his recorded analysis is correct. Interestingly, he recorded a

third data interpretation statement: “as ribosomes increase, waste decreases.” This statement, in addition to being incorrect, has no relation to anything previously observed, stated, or tested for as indicated in this student’s files. It is somewhat unclear as to where the student gathered this information, but his other statements regarding the mitochondria demonstrate some ability to follow the scientific method of observing, hypothesizing, experimenting/controlling for variables and data interpretation.

Embedded question 165245

Consistent with his initial observations around the cell, the student correctly answers the embedded question about mitochondria responsible for energy within the cell. This indicates that despite limited content understanding of the cell, interactions within the microworld lead to the student’s understanding the function of mitochondria as it relates to the cell.

Problem Scenario 2:

In question 161633, the students suggests that to “add more vacuoles” would make the cell healthy. This statement is partially correct but he does not indicate what kind of impact the addition of vacuoles would have upon the cell. He states his reasoning behind adding vacuoles is “cause I was exploring I seen I put four” which is too vague to interpret as he does not specify what he put in the cell, nor what that placement caused to happen within the cell.

In the hypothesis widget, the student records two different hypotheses. The first states “as the nucleolus increases, waste decreases” and the second is “as the vacuole increases, waste decreases.” In his original observation, the student does not indicate that the nucleolus has an effect upon the cell. His second hypothesis states that the “as the vacuole increases, waste decreases”, which is consistent with his initial observation from question 161633 that adding the vacuole would make the cell healthy.

To test his hypothesis, he recorded three different cell statuses. Status one and two were the original state of the cell. The third status had an increased number of vacuoles from the original of two vacuoles to four as well as an increase in the number of lysosomes from two to six. The data does not demonstrate that he controlled for variables but his additions of organelles did cause the cell to be almost completely healthy which would indicate that he did somewhat discern what organelles were important for this scenario as indicated in the log files.

Embedded questions 165248 and 165257

Student 4 correctly identified lysosomes being added to the cell in order to make it healthy but incorrectly answered the second embedded question about vacuoles increasing water. These results could indicate partial understanding of both the function of the lysosome and the vacuole. Because the log files do not indicate controlling for variables, it might be possible that his inferences about organelle function are incorrect based upon the data he collected, as evidenced by his recorded cell statuses in the log files.

Post Test Results

After the completion of the microworlds, student four achieved 33% correct on their post-test, indicating possible gain compared to the pre-test. The data for question 6, 1656478 was unable to be recovered, so no analysis of gain from Scenario 1 regarding the ‘powerhouse’ can be assessed. The student answered the questions the same on the posttest as the pretest except for question 8, 165680. Question two (165674) is another untargeted question that the student did not answer correctly. Multiple choice questions three (165675), four (165674), and seven (165679),) were all answered incorrectly. The student also correctly answered question 8 (165680), the difference between lysosomes and vacuoles. As this question was targeted by problem scenario two, it is possible that student four had some small amount of content gain.

Student Five

Background Information

Student 5 is a female aged 13 and in the seventh grade. She reported her favorite classes as Reading, Social Studies, and English. Her perception towards science is that she enjoys it sometimes and finds it somewhat easy. Overall her grades in science were in the D range and classes as a whole were in the C range.

Content Knowledge Pretest Results

Student 5 correctly answered 2 out of 8 questions, earning 22%. She correctly answered untargeted questions one and two (main problem and 161648). These indicate a very broad understanding of cells, but her knowledge may not be very specific since another general untargeted question (161654) on animal cells was answered incorrectly. This indicates that the student has limited background knowledge about cells. The targeted questions 161651, 161652, 161654, 161656, and 163933, which are focused on organelle definitions, were incorrectly answered. For the open response question on mitochondria (161655), the student stated that she did not know the answer. The responses to the pretest are consistent with little to no prior content knowledge.

Problem Scenario 1:

Despite an indication that student five has limited to no prior knowledge of organelles from the content pretest, the student was able to correctly identify the problems with the cell presented in scenario one (159815), “The problem with this cell is that it is missing energy & the life & the energy helps the cell. without that it wont make the cell healthy." As suggested by the pretest, the student had no prior knowledge of organelles and when asked how to make the cell healthy (159816), the student stated that she did not know the answer.

In Problem scenario 1 (159817) the student's hypotheses targeted the cell's lack of mitochondrion. She stated in the hypothesis widget that "as mitochondria increased, the energy increased". To test this hypothesis, she recorded five cell statuses. The first four recorded statuses in the log files was the original status of the cell. No change in variables was indicated. On the final recorded status, she did change one variable, the mitochondria. She increased the number of mitochondria from the original amount of two, to a final amount of eight. She potentially tested her hypothesis on the cell without recording any of her progressive changes. Status five does indicate that she did test her hypothesis due to the fact that she only changed the variable she identified in her original hypothesis, as evidenced by the log files.

Her analysis indicated the same in the data widget; mitochondria increase caused an energy increase. The student's interaction with the cell is indicative of consistency in testing her stated hypotheses. She is methodical and demonstrates skills at observing, hypothesizing, testing, and analyzing data in an organized manner even with what appears to be minimal to no evidenced content knowledge.

Embedded question 165245

Through the student's testing within the microworld, she comes to the correct conclusion that mitochondria influence the energy, as indicated by her response to this question that there is not enough mitochondria. Despite starting off with no organelle knowledge, interactions with the microworld indicate, as per log files, the student gained content knowledge with regard to the role of the mitochondria. This shows that the student is influenced by her experimenting within the microworld in order to actively arrive at that conclusion that energy is increased through mitochondria.

Problem Scenario 2:

Student five shows a strong skill at relying on scientific observations in question 161663 when asked to identify the problem presented in scenario two. She states that she can make the cell healthy by removing the waste and adding in water at the same time, increasing the life gauge. This is indicative of the student's observations of the gauges and also shows her understanding of the cell. By adding in water and removing waste, she is able to hypothesize that the life gauge is dependent on these factors, rather than just energy alone. At this point, it is evident that the student understands that certain organelles are responsible for maintaining the overall health as she points out that with waste and low water, the cell's life bar is not at an optimum level.

In the hypothesis widget, the student records two hypotheses. The first states "as the lysosome increases, waste decreases" and the second is "as the vacuole increases, water increases." Both of which are accurate hypotheses. To test her hypothesis, she recorded two different cell statuses. Status one had a change from the original state of the cell from two vacuoles to three. This was the only organelle which she added. The second status had an increased number of vacuoles to four as well as an increase in the number of lysosomes from two to six. Her changes in the second logged status caused the cell to have optimum levels for a healthy cell. The data is inconclusive as to whether she controlled for variables but it does indicate that she was methodical in inquiry: from her initial observations, to her hypothesis, and her experimental proceedings. These demonstrate through the collected data, that she has a solid foundation in the scientific method.

In the data interpretation widget, the student formulates three statements. The first and second of which are conflicting "as lysosomes decrease, waste decreases" and "as lysosomes increase waste decreases." This does indicate that she understands that the lysosome is related to the

amount of waste in the cell, however, it is not an accurate interpretation of the data she collected in the log files. Her final analysis states “as the vacuole increased, water increased.” This statement is a correct assessment of the data she recorded in the table, as confirmed by the log files. She demonstrates sufficient ability in the scientific method as shown through her observation, hypothesizing, and recording of data, but her interpretation of results is not quite accurate.

Embedded Questions 165248 and 165247

The student is able to correctly answer both embedded questions in response to this problem scenario. Correctly answering question one indicates that the student is able to distinguish between multiple variables in a single scenario, which leads to correctly answering the question – identifying individual functions of specific organelles targeted in the scenario.

Post Test Results

Student five showed no net gains in content knowledge as measured by the post test, since her overall score was 22%. Targeted questions that were asked in the microworlds were once again given an incorrect response and the student only correctly answered the same untargeted questions she had previous answered in the pretest, the main problem and 165674. Overall, her content knowledge in the microworlds indicates that she was actively learning during the scenarios, but during the post-test when asked to answers questions targeted by the microworld, she was unable to answer correctly.

Student Six

Background Information

Student 6 is a male aged 14 and in the eighth grade. His favorite classes are history and reading. He finds science classes somewhat easy and as such enjoys learning science sometimes. His overall grades are in the C range.

Content Knowledge Pretest Results

Student six had an overall score of 11% on the pretest. The only question answered correctly was question three, 161651, which focused on protein production and transport. Every other question was answered incorrectly. The lack of correct answers on the fundamental content items is consistent with the student having no prior content knowledge.

Problem Scenario 1:

Since it was inferred from the content knowledge pretest that student six had no previous content knowledge of biology, this was once again evident in his observation in scenario one. He correctly identified the lack of energy in the cell, but at the same time, inferred that the cell would still "last long" since it had a good protein life. This shows that student six was able to base their hypothesis from the displayed scenario but not from their prior knowledge.

In the hypothesis widget, the student states, "as the nucleus increases, waste decreases," as the nucleolus decreases, energy increases," and "as the nucleus becomes one, energy decreases." The student does address the issue of lack of energy in two of his hypotheses. He also only records one cell status, verified in the log files, which does not show any change in organelle amounts or any experimenting within the microworld.

The data interpretation widget shows the student made two statements about the cell: "as the endoplasmic reticulum decreases, waste decreases" and "as the vacuole increases, energy increases." Neither of these statements is correct nor do they indicate any sort of interpretation of data by the student.

Embedded Question 16245:

The answer given by the student was “not enough nuclei” which was incorrect, indicating the student was not paying close attention or did not fully recognize the role of mitochondria in a cell.

Problem Scenario 2:

Based on the student’s response, "nothing is really wrong only thing its that it needs more water and needs to waste more", it is once again inferred that his understanding of the scenario is derived from the gauges as opposed to any biology content knowledge he may have had going in to the activity. He correctly indicates the gauges that are low, but does not hypothesize which organelles are necessary to retain balance, but only that the reason he knows this is “because it show it on the picture above.” These responses are also consistent with no prior content knowledge.

In Problem Scenario 2 (161665), Student 6 hypothesizes via the hypothesis widget that “as the nucleolus decreases, energy decreases” and that “as the nucleus becomes one, waste decreases”. These are not consistent with his original observations as evidenced by his recorded statements for question 161663. The student records no cell statuses in the table as seen in his log file. Any inferences about his ability for scientific inquiry are unable to be deduced in regard to experimentation and data collection.

Using the data analysis widget he provides two analyses: “as the nucleus becomes one, water increases”, “as the golgi body decreases, water decreases”, and finally, “as vacuoles increase, waste increases”. Neither of these statements is accurate and, given his inquiry skills as shown in

the progression from observation, to hypothesis, to no recorded data, and random data analysis, it is likely that the student did not attempt to interact with the microworld.

Embedded Questions 165248 and 165247

The student correctly answered question 165248, which required them to make a distinction between vacuoles and lysosomes. However, he incorrectly answered question 165257, stating endoplasmic reticulum was responsible for water content.

Post Test Results

The posttest score for this student was 22%, however, his gain increased by one question, an untargeted question asked about cellular definition and a targeted question on the differences between vacuoles and lysosomes. He correctly answered the main question as well as question 165680, which was targeted by Problem Scenario 2. Due to incorrectly answering every other question other than main question and 165680, this suggests the subject may have guessed on the pretest, and did not gain any content knowledge about the endoplasmic reticulum. Since the targeted question answered correctly was covered in the last scenario of the microworlds, it is suggestive that the student did in fact retain some minimal knowledge that later carried over into the post tests.

Student Seven

Background Information

Student 7 is aged 13 and is a male in the eighth grade. His preferred classes are math and science. In terms of science classes, he enjoys learning about the concepts in science sometimes since he finds it easy as his grades are around the A range. In all classes, his grades are mostly in the B range.

Content Knowledge Pretest

Student seven scored a 22% on the pretest. The questions correctly are questions main question and 161652, which evaluate understanding of cell definition and endoplasmic reticulum differences. His answer to the open response 161655 was "one organelle its organelle because i dont know". The results are not conclusive enough to suggest prior content knowledge, as he only correctly answered 2 questions.

Problem Scenario 1:

The student initially observes the cell and states "this cell doesnt have enough energy and to make it healthy it would need some energy i think it would need more mitochondria." The student correctly observed that the cell was lacking in energy as well as which organelle might have an impact which was also correct. When asked to further explain, the student references his previous explorations within the microworld when he states "I think that it has low energy becuase it doesnt have enough lysosome and mitochondria. I think this because as i was testing everything i noticed that the gauges was going up as i put lysosome and mitochondria." Even though his identification of the lysosome was incorrect, the statement regarding the mitochoindria is correct and is consistent with content gain on the student's part such that he is actively learning from the microworld.

In the hypothesis widget, the student makes two statements, which were identical: "as the mitochondria increases, energy increases." The student correctly addressed the issue of lack of energy as well as demonstrated hypothesizing based upon his observation. He records six cell statuses, verified in the log files, the first three of which are identical but show that he did increase the number of mitochondria from two to three. The forth status reveals that he increased

the mitochondria to six in total. The fifth status is identical to the first three: he decreased the mitochondria to a total of three. In the final recorded status, he increased the number of mitochondria to five. The log files indicate the student had an excellent grasp of the controlling for variables strategy because he only changed one variable at a time, the mitochondria. He also demonstrated his ability to observe, hypothesis, and experiment in a consistent and scientific The student made one statement using the data interpretation widget: “as the mitochondria increases, energy increases.” Not only did the student interact with the microworld demonstrating excellent use of the control for variables strategy, but he successfully interpreted the data to arrive at the correct conclusion.

Embedded Question 165245

Interaction within the microworld allows the student to correctly answer the embedded question, which asks what caused the energy gauge to be low. The student was able to identify the lack of mitochondria as principal to this scenario.

Problem Scenario 2: 161665

Student seven correctly indicated that the cell does not have enough water and also identified that it has too much waste, though he did not explicitly state anything regarding the gauges. He reasoned that there were ["not enogh vacoule for the water and not enough of ribosome." He did correctly identify that the vacuole was important in regards to water suggesting possible prior content knowledge.

In Problem Scenario 2 Student 7 hypothesized via the hypothesis widget that “as the vacuole increases, water increases” and that “as the nucleus decreases, energy decreases”. His first hypothesis was clearly testing part of his observation, however the second was not consistent with his original observations as evidenced by his recorded statements for question 161663.

The student recorded five different cell statuses in the table as seen in his log file. The first status showed that he increased the number of vacuoles from its original state of two to a total of five vacuoles. In the second set of recorded data, he decreased the number of vacuoles to four. The last three recorded cell statuses showed a decrease in vacuole number to two but an increase in the number of nuclei to 4. He clearly demonstrated use of the control for variables strategy as he only changed one variable while testing his hypothesis regarding vacuole addition. It does not show if he used control for variables strategy while assessing the nucleus's impact upon the cell, but it is clear that this student was testing both of his hypotheses.

Using the data analysis widget he provided two analyses: "as vacuoles increase, water increases" and "as the nucleus decreases, energy decreases." The first statement was a correct inference by the student but he incorrectly stated that a decrease in nuclei caused a decrease in energy. It is clear that the student was successful in using a methodical approach, but it is unclear as indicated by his response in the data interpretation widget whether the student was able to make a valid conclusion based upon his recorded cell states.

Embedded Questions 165248 and 165247

The student incorrectly answers the first embedded question, which focused on the difference between vacuole and lysosome function. The second question in regard to vacuole function was answered correctly. According to the log files, the student only tested the effects of the vacuole and nucleus, therefore, in conjunction with the log files, the fact that he did not answer the first question correctly suggests that he did not attempt to experiment to test the functions of the other organelles.

Post Test Results

With a score of 77% on the content knowledge post test, student seven showed an impressive gain of 55% from the pretest. On the whole, this indicated that the student gained content knowledge from the microworlds. The questions he incorrectly answered were an untargeted question on cell structures (165674), and item identifying organelles that affect protein production (165675). In question 165675, the student answered “nucleolus” in his post test response, which while incorrect, this suggests that the student was not focused on the protein gauge, as this was not specifically targeted by the microworlds, but rather in the explore phase. If protein production was specifically included in a microworld – potentially a future one – this student might have shown a gain in knowledge, as this would be targeted in more detail, allowing student seven to interact in depth. In question six (1615678,) he stated ” the mitochondrion [was the powerhouse] because it is gives energy. Thus far this is the only student who made this correct inference, demonstrating successful interaction with the cell and inference-making beyond the information given. Overall, student seven shows dramatic gains in the post test, strongly indicating that his attention was on the microworlds and while interacting through them, he made positive gains on cellular knowledge.

Student Eight

Background Information

Student eight is a 13 year old male in eighth grade. He has specified that his favorite classes are math and gym. He finds science class to be usually easy and he enjoys learning it at all times. His grades are generally A’s including those in science classes.

Biology Pretest

This student scored a 44% on prior biology content knowledge. The student correctly answered the main problem and question two (161648). This showed that he had a general understanding of what a cell is and how it is held together by the cell membrane. However, most of the questions dealing directly with organelle functions were answered incorrectly: question three (161651), question five (161654), question six (161655), and question seven (161656). Question four (161652) dealt with organelle structure and was answered correctly. This showed that the student may have remembered basic structure, but had very little prior knowledge about the roles that organelles play in the cell. This suggests that he lacked an understanding of protein production, energy production, and water storage. He began his answer to the open response of question six by declaring "I don't know, I think…" He then stated that the "powerhouse" of the cell is the nucleus because it "controls all of the cell". This is consistent with the general misconception discussed in the background section, that students often attribute all of the main roles to the nucleus (Berthelsen, 1999). It is interesting to note that he incorrectly answered about the function of the vacuole in question seven, but correctly differentiated between the vacuole and lysosome in question eight (163933). Over all, student eight had a limited understanding of the cell, but no comprehension as to organelle function.

Problem Scenario1

When presented with the picture of the unhealthy cell, student eight was able to clearly hypothesize what was wrong with cell in question 159815, and then explain the mitochondria needed to be added to make the cell healthy. This showed an apparent understanding of the basic organelle structure and function. When asked to support their answer in question 159816, he did not indicate that he looked at the gauge. His explanation suggests that he guessed that the

mitochondrion was a food source. Although “food” is broken down for energy, this statement was false because it is not the mitochondria that provide food, but rather they convert the energy.

In question 159817, the student hypothesized that as the number of mitochondria increases, the energy also increases. His other hypothesis was that “as the number of vacuoles decreases the waste level increases”. Although only the first of these two statements is relevant to the problem scenario, it should be noted that both of these statements are correct. He then proceeded to test his hypotheses and recorded three of those trials. His first recorded trial was after he had already found that the mitochondria increased energy because the energy bar was not at its initial 25%, but at 75%. Then he added 2 more mitochondria and reached the “ideal,” healthy cell. Then after completing this he continued to experiment. He once again removed mitochondria, and then also removed one vacuole. This caused the energy, waste and water bars to change at once. To look at the specific change caused by the removal of the vacuole, he made energy 100% again and recorded the cell with only one missing vacuole. This is a good example of his understanding of CVS.

From this experimentation he made the following conclusions: “As the number of mitochondria increases, the energy increases”. Then “as the number of vacuoles decreases, the waste increases”. Although he did not explain the decrease in water, the fact that he experimented beyond what was required by the activity suggests that the student understood the process of inquiry and was curious to explore. Overall this student clearly demonstrates inquiry skills, and gains from his interaction with the SimCell.

Embedded question 165245

This student did not seem to have much prior knowledge of the cell organelle functions as evidenced by his answers in the pretest, however his skillful experimentation and interactions

with the microworld seemed to have helped him correctly answer this question and understand that mitochondria increase the level of energy in the cell. This is seen in his interactions with the cell and logged cell statuses.

Problem Scenario 2

In question 161663, Student eight describes what he thinks is wrong with the cell. He thinks that the cell "lacks water and a proper waste system." He then goes one to predict that the cell will need more vacuoles. Although he does not mention the lysosomes, it is clear that he has prior content knowledge about the cell, its necessities, and how it functions. He is applying that knowledge to this case, when he proposes a possible solution. His answer to question 161663 is that the vacuole is a storage system for water. He does not refer to the gauges but rather an "experiment", which he does not describe further. It is possible that he is referring to the first problem scenario in which he experimented with the vacuoles and their role in the cell. This shows that he is thinking about the information that he already knows and using it to solve a new problem.

Within the scenario, question 161665, student eight uses the hypothesis widget and construct the following hypothesis: "As the vacuoles increase, water increases", and as the "lysosomes increase, waste increases". Using the data table, he recorded only one trial. This trial still lacks one vacuole and one lysosome. Because he did not show more trials, we cannot be sure whether or not he controlled for variables. However, he is clearly testing his hypotheses because those two organelles are the only ones that are not at optimal levels. It is interesting to note that this student seemed to have misinterpreted the waste gauge because it is the only one that *decreases* to make the cell healthy.

With the data analysis widget, the student concludes that: “as the vacuoles increase, water increases”, and “as the lysosomes increase, waste increases”. This is exactly what he hypothesized. The student seemed to follow the steps of scientific inquiry carefully throughout his experimentation, as shown by his approach to hypothesize about his observations as well record data and analyze it.

Embedded questions 165248 and 165257

Student eight correctly answered both these questions. Not only could he describe the function of the vacuole correctly, but he could also differentiate between the role of the vacuole and the lysosome. This is also consistent with the student having prior content knowledge as well as successfully interacting with the microworld as demonstrated by responses to the embedded questions.

Biology Post Test

This student scored a total of 56% on the content post test. His responses between the two content tests were the same except that he answered one more targeted question correctly in the post test. This shows some content gain after the microworld activity. The first question (main problem) and question two he answered correctly. Question three was answered incorrectly but question 4 was answered correctly. Question five tested content and organelle function/structure-based question, which the student answered incorrectly. His answer to the open response did not change from the pretest, as he thought the “powerhouse” of the cell was the nucleus. This further suggests possible misunderstanding of the question. Question seven and question eight were answered correctly, which suggests that he understood the distinction of the functional differences between lysosomes and vacuoles.

Student Nine

Background Information

Student nine is a 13 year old male in seventh grade. His favorite classes include math and social studies. He thinks science class is somewhat easy, and he sometimes enjoys learning it as a subject. His grades are mostly in the B range, but his science grades fall in the C range.

Biology Pretest

Student nine scored 33% on the biology pretest. He correctly answered questions one (main), two (161648), and five (161654). All of these questions test for general understanding of the cell and then more specifically the animal cell in questions two and five. He then answered all of the other questions incorrectly. These questions all pertained to cell structure and function. His answer to the open response of question six (161655) suggests that he did not understand the meaning of "organelle." He answered that the "powerhouse" organelle is the "brain because it controls all the power in your (body), which comes from the word house from powerhouse." Interestingly he breaks down the word "powerhouse" into "power" and "house," but then incorrectly defines them so that the *brain has power*, and *the body is like a house*. Although it seems that the student put effort into answering the open response, it is clear that he did not possess knowledge of organelles and their functions when beginning the activity.

Problem Scenario1

When given the picture of the first unhealthy cell, student nine identified that the cell had low energy for question 159815, however, he mistakenly believed that water storage and energy production were linked and controlled by the vacuole. Question 159816 asked to support their answers and give an explanation, but he skipped this question. This suggests that the student can read the gauges and obtain quantitative information from them, but he does not have sufficient content knowledge to fully understand the functions of the organelles.

Using the hypothesis widget of question 159817, the student gave the following two hypotheses in order: “As the number of vacuoles increases, the energy increases”, and “as the number of mitochondria increases, the energy increases”. This shows that his first guess is that the vacuoles control energy. He may have explored to find that it was in fact mitochondria that do this. His two trials indicate that he had removed vacuoles from the cell prior to recording because both the water and waste levels are not optimal, as shown by his log files. This showed that he was testing his initial hypothesis. When he saw that his vacuole-hypothesis was not supported, he tested the mitochondria-hypothesis. Between the two recorded trials, the only variable he changed was the addition of one mitochondrion, resulting in an increase of energy. This shows that the student used CVS to give minimal evidence that the cell’s energy is controlled by the mitochondria. He did not provide proof of achieving an ideal cell.

From this experimentation he made the following conclusion: “As the number of mitochondria increases, the energy increases”. This correctly targeted the problem in the cell and solved it. At the end of this activity student nine demonstrated knowledge of basic inquiry skills.

Embedded question 165245

This student correctly answered that the cause of the problem in the cell was that it did not have enough mitochondria. Although the student started with very little knowledge about the functions of organelles, he was able to test his hypotheses and communicate his conclusions by answering this question.

Problem Scenario 2

This student identified that the cell had low water and high waste. In question 161663, he explains that adding vacuoles would eliminate such a problem. As many of the other students, he did not mention lysosomes as having an effect on waste. In answer to question 161663 he says

"the vacuole is water…" This suggests that the student can link the structure with the function of the organelle. He continues to say that water gives the cell "energy." This is a misunderstanding of the word "energy." He does not make any reference to the gauges in his answer, and gives very brief descriptions.

Within the scenario, question 161665, he hypothesizes that: "As the cell has a higher quantity of vacuoles and lysosomes, the waste decreases". Using the data table, he recorded four trials. The first trial was optimal in all aspects except for the waste. This meant that only the lysosomes were being tested. Then the ideal cell is reached. The student then removes some of the vacuoles and lysosomes, then again replaces them to build the ideal cell. These trials demonstrate that the student was controlling for variables and checking that he could repeat his own results. This shows advanced inquiry skills.

In his data analysis, the student concludes that: "as the vacuoles and lysosomes increase, the waste level decreases". He fails to mention any hypothesis about the water level in the cell. This caused him to lose half the points that he may have received. Over all, the student followed the steps excellently and was able to communicate these findings through his analyses of the data.

Embedded questions 165248 and 165257

This student correctly identified that the lysosome does not affect water in the cell, but then contradicts this when he answers the next question. The wording of the these two questions is very similar. It may be that the difference between the two questions was hard to process without critical thinking and understanding of the organelle functions.

Biology Post Test

This student scored a total of 22% on the content post test, lower than his pre test. The only questions that he answered correctly were 165674 and 165676. His answer to the open response

changed from calling the “brain” a power house, to saying that the vacuole was the “powerhouse” because it controlled energy. This misconception was also part of his initial prediction for what was wrong with the cell in problem scenario 1. This means that he did not thoroughly understand the conclusions that he made. His responses between the two content tests ranged, as he earned credit on different questions. Some of the question that he initially answered correctly, he answered incorrectly the second time. This suggests that he either guessed on the tests because he lacked content knowledge, or that he was frustrated by the length of the activity and randomly chose answers.

Student Ten

Background Information

Student ten is a 14 year old female in seventh grade. She has indicated that her favorite classes are English and Social Studies. She thinks science class is somewhat easy but she sometimes does not enjoy learning science. Her general grades fall in the C range, while her science grades are in the D range.

Biology Pretest

This student received a score of 44% for pretest biology knowledge. She correctly answered the main problem and question two (161648). This showed a very basic understanding of the definition of a cell and how it is enclosed. Her content knowledge of organelle structure and function, however, proved to be less advanced. She incorrectly answered questions three (161651), four (161652), five (161654), and six (161655). She responded to question six by saying that she did not know the answer. She correctly answered questions seven (161656) and eight (163933) about vacuole and lysosome functions. Overall, student ten had some general understanding of cells but a limited understanding of organelle functions.

Problem Scenario1

From the diagram of the cell, student ten realized that the cell lacked energy. However, based on her description for question 159815, she also thought that the cell had too much waste. This may have been because the waste gauge worked opposite of the other gauges, in that an empty waste bar was ideal, and a full waste bar was detrimental to the cell health. Question 159816 asked to support their answers and give an explanation, but she only repeated that the cell needed energy and had too much waste. Her responses prior to exploring the cell suggest that she has little or no understanding of cell function, but has the basic skill at reading the gauges and interpreting how they affect cell health.

Using the hypothesis widget of question 159817, the student gave the following two hypotheses in order: “As the number of nucleoli increases, the energy increases”, and “as the number of nucleoli decreases the waste decreases”. Both of these hypotheses are incorrect, which is consistent with the idea that this student does not have content knowledge about the organelle functions. She only recorded one trial several times using the data table widget. In this trial the energy gauge is full, but many of the other gauges are not at optimal levels. The changes in the other gauges show that the student did not control for variables and did not understand how to test her hypotheses. The changes that she made in the number of organelles were not well organized and may have been random. From this one trial, it is unclear whether she understood which organelle was responsible for the increase in energy.

From this experimentation she made the following conclusion: “As the number of ribosomes decrease, the waste increases”. This analysis is not only irrelevant to the initial problem, but it is also a false observation. The student’s activity in this problem scenario of the microworld

suggests that she has a poor understanding of cell biology and lacks important inquiry skills. This student may need further assistance to comprehend the material.

Embedded question 165245

Student ten incorrectly responded to this question. Her response was that the cause of the problem in the cell was due to too few nuclei. This did not pertain to the activity because she did not test this hypothesis. If she had, she would have seen that an addition nucleus in the cell is actually fatal to the cell. This may mean that she was not taking the activity seriously. Her low content knowledge and haphazard experimentation did not allow her to acquire content knowledge from this activity.

Problem Scenario 2

This student did not answer both questions in 161663 seriously. This may be representative of her lack of prior content knowledge, or lack of motivation.

When she reached the hypothesizing widget in the activity it seems that she is randomly guessing because her two hypotheses are that: “As the number of nucleoli decreases, the protein in the cell will increase”, and, “as the number of lysosomes reaches zero, energy in the cell decreases”. Neither of these statements is based on any possible observations that the student could have made from looking at the problem scenario. These might suggest that the student was not engaged in the task.

Using the data table, she recorded the same trial twice. The trials were both of the initial problem scenario, indicating that she may not have even attempted this problem. Her inquiry skills cannot be interpreted here, because there is not enough information about her actions in the activity.

In his data analysis, her responses are: “as the number of ribososmes becomes one, protein production decreases,” and “as the number of nucleoli becomes one water storage decreases”. Although the first statement is a correct statement, it does not apply to this problem scenario, which deals with water and waste. The second statement, again suggests that she was haphazardly clicking the hypothesis widget to get through to the next activity. She does not test her hypotheses, and does not have the right data to draw these two conclusions.

Embedded questions 165248 and 165257

Both of these questions were answered incorrectly. Over all, student eleven did not earn any credit for problem scenario 2.

Biology Post Test

This student scored a total of 11% on the content post test, the lowest score among the students. She only answered one multiple choice question correctly (165679) When guessing, there is a 25% chance of correctly answering the question. This student scored well below this, The fact that her score decreased also suggests that she was running through the activity in an attempt to complete the task with little or no effort. For example, she wrote that she did not know the answers of many of the open response questions, instead of guessing like some of the other students tried. This test was not a good reflection of her content knowledge.

Student Eleven

Background Information

Student eleven is a 14 year old male in eighth grade. His favorite subject is math. He finds science class to be somewhat easy, but he is neutral about learning the subject. His general grades, including his science grade are in the A range.

Biology Pretest

This student had the highest score of 67% on the biology content pretest. He correctly answered the main problem as well as question two (161648), showing his grasp of basic cell knowledge. His answer to question five (161654), generalizing all animal cells, was incorrect. However, he then answered questions four (161652), six (161655), seven (161656), and eight (163933) correctly. These questions were all about the structures and functions of organelles. He incorrectly answered question three (161651). This question asked to choose the organelle that did not contribute to protein production. This student answered "ribosomes," which are the main protein producers. This is interesting because the question is worded in a way to trick the student using the word "except." Because he answered all of the other cell-function questions correctly, it may even be that he fell for this trap. This student was the only one of the eleven to receive credit for the open response of question six. He correctly indicated that the mitochondria are the "powerhouses," however in his description, he said that, "all the nutrients get transported there and it works just like a factory." This did not show a clear understanding of the mitochondria's role in the cell, therefore he only received half of the credit. In general, this student preformed very well on the pre test and was knowledgeable in cell biology from the beginning of the activity.

Problem Scenario1

This student demonstrated an understanding of the problem in the cell presented. His answer to question 159815 explained that the energy was low and that the mitochondria were responsible. He clearly states that the problem could be solved by placing more mitochondria in the cell. Question 159816 asked to support their answers and give an explanation. He did not explain that his answer was based on the energy gauge, but he had a rich explanation about how food and nutrients are converted to energy with the help of the mitochondria. His thorough responses

show that he had prior content knowledge and understood how to observe and interpret a visual model of a cell.

With the hypothesis tool on question 159817, the student gave the following hypothesis: “As the number of mitochondria increases, the energy will increase”. During his experimentation he recorded three trials. He recorded the initial state of the cell with low energy, then the finals state of full health, then again the initial stage. His prior content knowledge suggests that he knew how to fix the cell, but it is unclear whether he made the cell healthy with his first attempt. He showed evidence that the mitochondria were responsible for increasing energy, but he did not record any further investigations. This showed that he focused on testing his hypothesis and had proper use of the control for variables strategy.

From this experimentation, he reached the following conclusion: “As the number of mitochondria increased, the level of energy increased”. This analysis was consistent with his initial hypothesis. This student’s ability to hypothesize, test, and communicate his conclusions in the Microworld activities suggest that he has a strong grasp of content knowledge and good inquiry skills.

Embedded question 165245

Student eleven successfully indicated that the cause of the problem in the first problem scenario was the lack of mitochondria in the cell.

Problem Scenario 2

This student identified that the cell’s level of waste was high. In question 161663, he explains that by adding lysosomes, one could reduce the waste. The fact that this student chooses to talk about lysososmes shows that he has knowledge of the cell and its organelles. Although his diagnosis of the cell is correct, it is only partial. He fails to mention the role of the vacuole in

water and waste storage. Additionally, he does not give an explanation or source for his diagnosis of the cell.

In question 161665, he uses the widget to hypothesize that: “As the number of lysosomes increases, the waste level decreases”, and “as the number of vacuoles increases, the water level increases”. This shows very thorough reasoning of the state of the cell. This showed prior biology content knowledge. Using the data table, he only recorded the initial condition of the cell at the start of the activity. It is unknown whether he tested his hypotheses or if he used CVS. As a result, it is hard to draw conclusions about his inquiry skills.

In his data analysis, the student concludes that: “as the lysosomes increase, the waste level decreases”. He fails to make any conclusions about the water level in the cell. This may mean that the student never tested his second hypothesis. It also may indicate some signs of fatigue and frustration if he forgot to take into account the other half of his predictions. Although this student came into the activity with prior knowledge, his inquiry skills were not apparent in this problem scenario, as evidenced by his poor use of the data recording widget. He does not communicate his data collection to provide proof of his experimenting.

Embedded questions 165248 and 165257

Although one of his hypotheses was not addressed in his conclusions, student eleven correctly answered both of these questions. This suggests that he obtained or reinforced some knowledge from this activity.

Biology Post Test

This student scored a total of 44% on the content post test. Although he had the highest pretest score and succeeded in the mircroworld activities, he scored lower on the post test. He correctly answered the first two questions (main and165674) and the open response (165678). His answer

to the open response did not change from the pretest, although it was shorter with less richness. Although he received full credit for it, the length of his response may suggest some fatigue/frustration. His responses between the two content tests ranged, as he did not earn credit on many of the questions that he had previously. He seemed to be guessing a lot more on the post test. Many of the targeted questions which he answered correctly in the pretest, which were again reinforced by the microworld, he answered incorrectly the second time. This student's performance is suggestive of the length of the test relative to a student's attention span. This is discussed further in the conclusions and implications for future research section.

Conclusions

As the existing methods of assessment have become outdated, there is a need for more interactive ways for students to learn and apply their knowledge. In developing the SimCell Microworld, we sought to address common student misconceptions in cell biology while assessing students of their knowledge in an engaging virtual environment.

Many of the students show content gain based on the biology tests administered before and after the Microworld activity. Students showed increased open response scores on the embedded questions within the Microworld, as compared to the open response in initial assessment. In considering the richness of responses, one can conclude that while interacting with the SimCell, students were more willing to think critically and apply their inquiry skills towards answering and understanding the problem scenarios presented to them. As explained in the results, there was significant variation in the answers to embedded open response questions in the microworld. Capturing these different levels of thinking and application of knowledge is important for future use of the microworlds as potential tools for assessment.

According to final remarks by several of the students, they thought the microworld was a “fun” way of learning about the cell. Such activities succeeded in engaging students while they interact with a dynamic learning environment. Providing students with automatic feedback to the choices that they make in the process of experimenting closely simulates hands-on laboratories. These virtual experiments help students develop the inquiry skills essential for their future education and life. Further advancements in this microworld will allow instructors to monitor the activity of students and have scaffold questions that aim to assess and tutor each student based on their individual needs.

Appendices

Appendix 1a: Inquiry Pretest

Hypothesis: If the amount of sugar increases then the candy bar will taste sweeter.
Which is the independent variable?

Comment on this question

Select one:

- The number of candy bars tasted
- The amount of sugar in the candy bar
- The sweetness of the candy bar
- The sweetness of the sugar
- The size of the candy bar

Submit Answer

Appendix 1b: Inquiry Pretest

Hypothesis: If the amount of sugar increases then the candy bar will taste sweeter.
Which is the dependent variable?

Comment on this question

Select one:

- The number of candy bars tasted
- The amount of sugar in the candy bar
- The sweetness of the candy bar
- The sweetness of the sugar
- The size of the candy bar

Submit Answer

Appendix 2a: 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.

a) What was the control group?

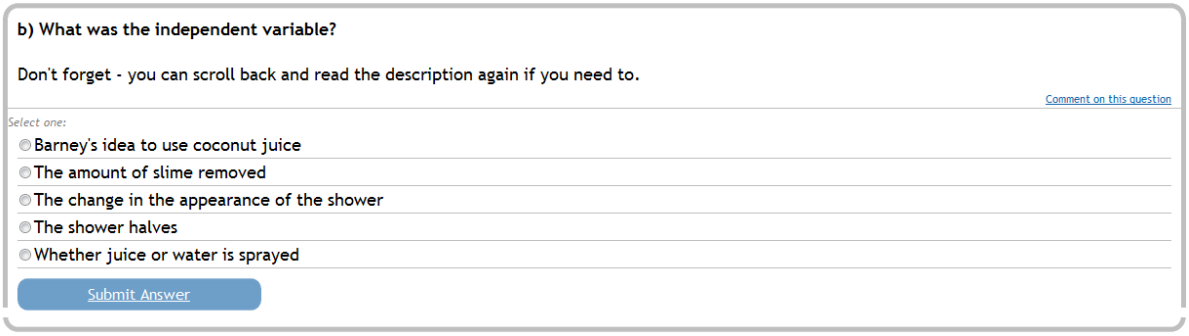
Comment on this question

Select one:

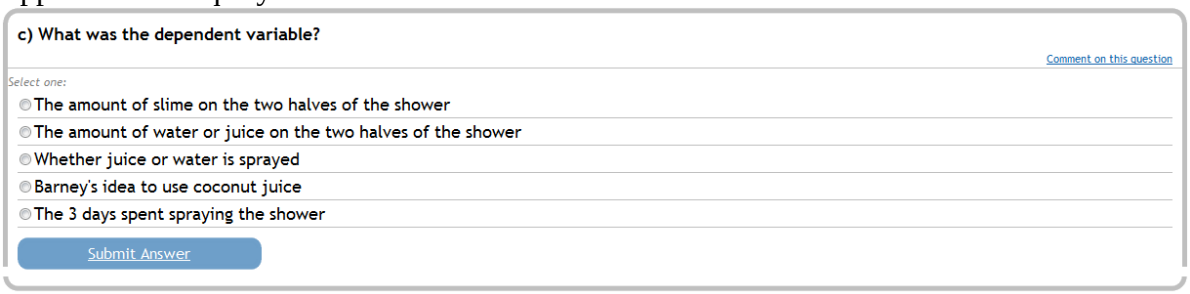
- Barney's idea to use coconut juice
- The half of the shower sprayed with water
- The half of the shower sprayed with coconut juice
- The 3 days spent spraying the shower
- The appearance of the shower

Submit Answer

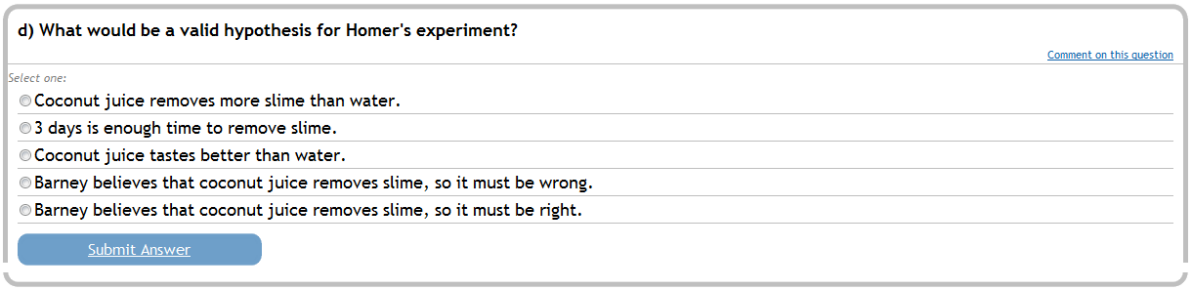
Appendix 2b: Inquiry Pretest



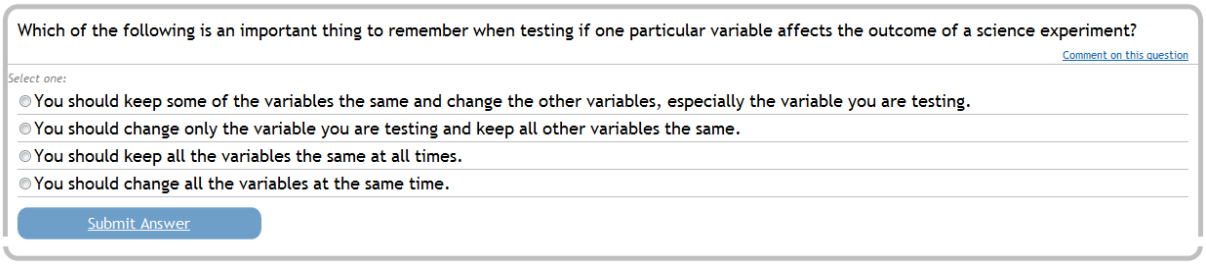
Appendix 2c: Inquiry Pretest



Appendix 2d: Inquiry Pretest

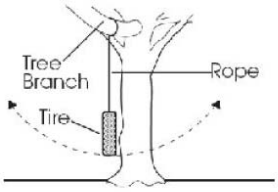


Appendix 3: Inquiry Pretest



Appendix 4a: Inquiry Pretest

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?

Appendix 4b: Inquiry Pretest

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

Appendix 4c: Inquiry Pretest

Explain your answer.

Comment on this question

Type your answer below:

Submit Answer

Appendix 5: Inquiry Pretest

Which statement describes the best procedure to determine if a vaccine for a disease in a certain bird species is effective?

Comment on this question

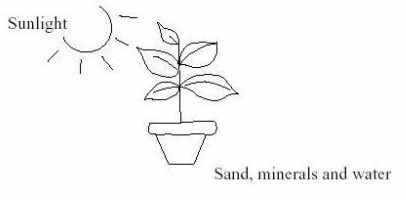
Select one:

- Vaccinate 100 birds and expose all 100 to the disease.
- Vaccinate 100 birds and expose only 50 of them to the disease.
- Vaccinate 50 birds, do not vaccinate 50 other birds, and expose all 100 to the disease.
- Vaccinate 50 birds, do not vaccine 50 other birds, and expose only the vaccinated birds to the disease.

Submit Answer

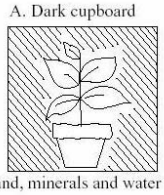
Appendix 6a: Inquiry Pretest

A girl had an idea that plants needed minerals from the soil for healthy growth. She placed a plant in the Sun, as shown in the diagram below.

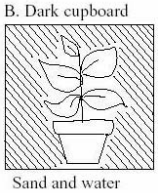


In order to check her idea she also needed to use another plant. Which of the following should she use?

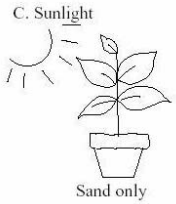
A. Dark cupboard



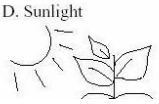
B. Dark cupboard



C. Sunlight

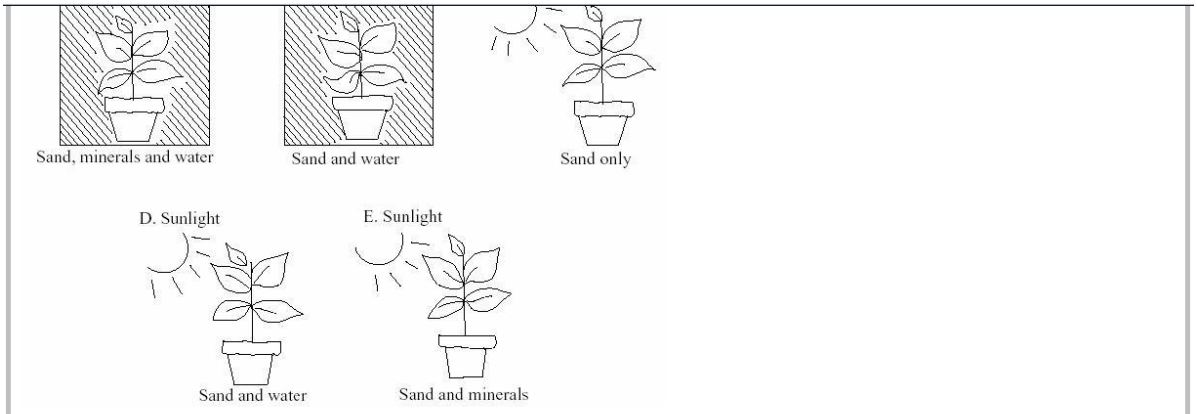


D. Sunlight



E. Sunlight

Appendix 6b: Inquiry Pretest



Comment on this question

Select one:

- A
- B
- C
- D
- E

Submit Answer

Appendix 7: Inquiry Pretest

To find out whether seeds grow better in the light or dark, you could put some seeds on pieces of damp paper and

Comment on this question

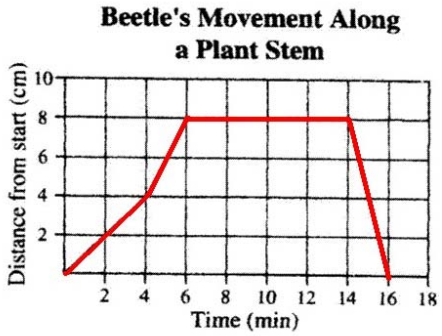
Select one:

- keep them in a warm, dark place
- keep one group in a light place and another in a dark place
- keep them in a warm, light place
- put them in a light or dark place that is cool

Submit Answer

Appendix 8: Inquiry Pretest

The graph below shows a beetle's movement along a plant stem.



During which span of time was the beetle not moving?

Comment on this question

Select one:

- from 0 to 4 minutes
- from 4 to 6 minutes
- from 6 to 14 minutes
- from 14 to 16 minutes

Submit Answer

Appendix 9: Inquiry Pretest

Curtis conducted an experiment to see if some liquids mix with Liquid X. His results are shown in the table below.

Results of Curtis's Experiment

Type of Liquid	Mixes with Liquid X
Gasoline	No
Vegetable Oil	No
Kerosene	No
Turpentine	No

Based on this data, what is the best conclusion?

Comment on this question

Select one:

- Liquid X cannot mix with any other liquid.
- Liquid X must be able to mix with some other liquid.
- Liquid X cannot mix with these four liquids.
- Liquid X can mix with most other liquids.

Submit Answer

Appendix 10a: Content Knowledge Pretest

What is the smallest unit that can perform ALL the functions of life?

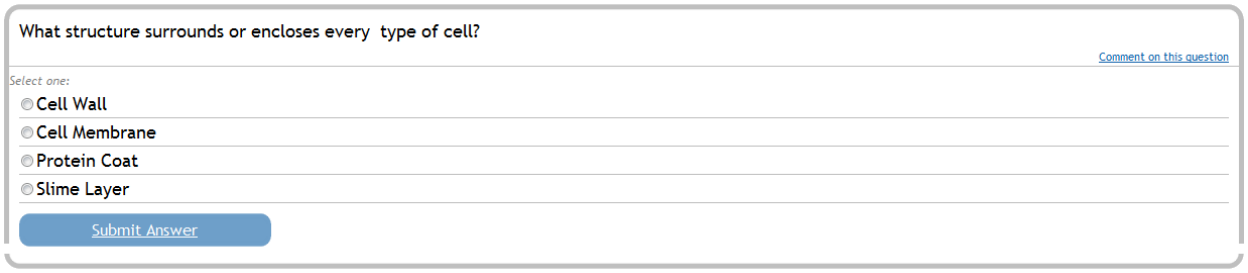
Comment on this question

Select one:

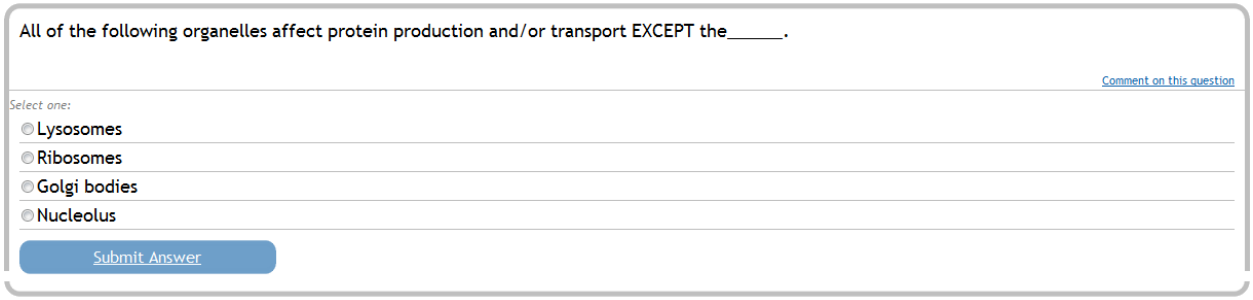
- DNA
- Cell
- Organelle
- Mitochondria

Submit Answer

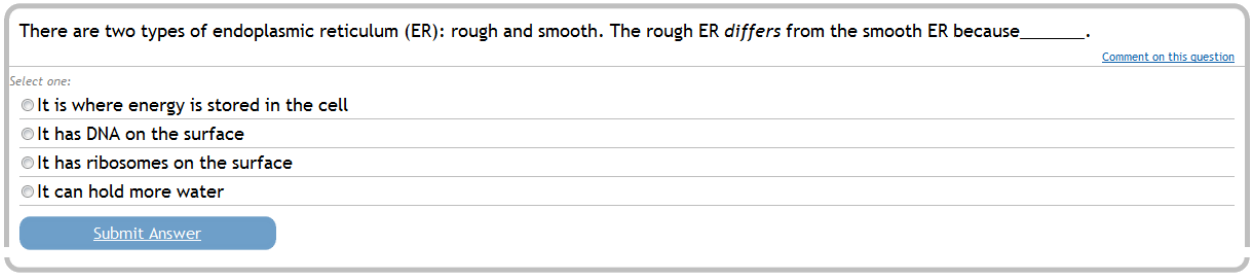
Appendix 10b: Content Knowledge Pretest



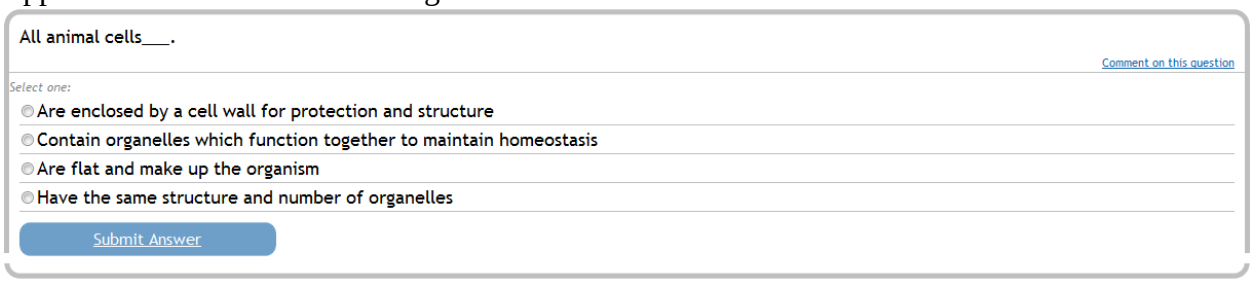
Appendix 10c: Content Knowledge Pretest



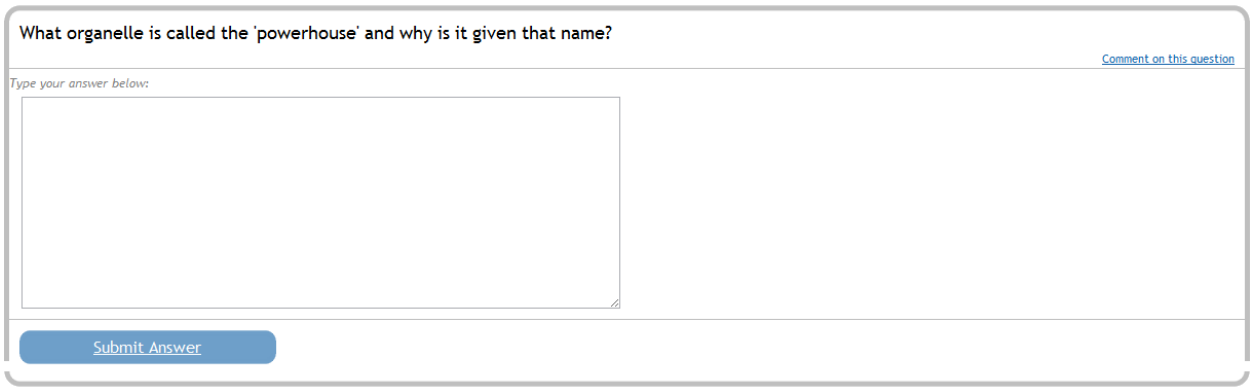
Appendix 10d: Content Knowledge Pretest



Appendix 10e: Content Knowledge Pretest



Appendix 10f: Content Knowledge Pretest



Appendix 10g: Content Knowledge Pretest

What role does the vacuole play in maintaining the health of the cell?

Comment on this question

Select one:

- It provides protein for cell function.
- The nucleus uses it for structural stability
- Isolates and exports waste from the cell and helps maintain water pressure
- Transports vesicles and proteins to and from the nucleus

Submit Answer

Appendix 10h: Content Knowledge Pretest

How does a lysosome differ from a vacuole in function?

Comment on this question

Select one:

- Lysosomes and vacuoles are both involved in waste storage but only vacuoles store water
- Lysosomes transport proteins while vacuoles only produce proteins
- Lysosomes and vacuoles both produce energy but lysosomes also store waste
- Lysosomes and vacuoles are the same and both transport water to the nuclues

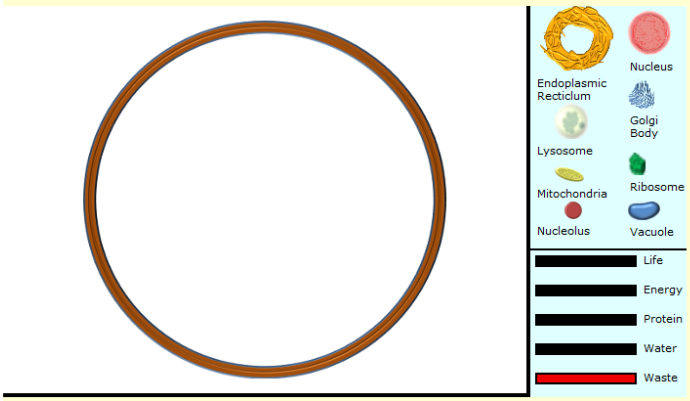
Submit Answer

Appendix 11a: Microworld Introduction

1) Explore the tools: There is an empty cell and a toolbox with a collection of organelles. To place an organelle into the cell simply drag it from the toolbox into the cell. To remove an organelle drag it from the cell back into the toolbox.
In the lower right corner you will see a series of gauges. The gauges represent the current health of the cell. Green represents a healthy cell and red represents an unhealthy cell. The gauges will change as you add or take away organelles.

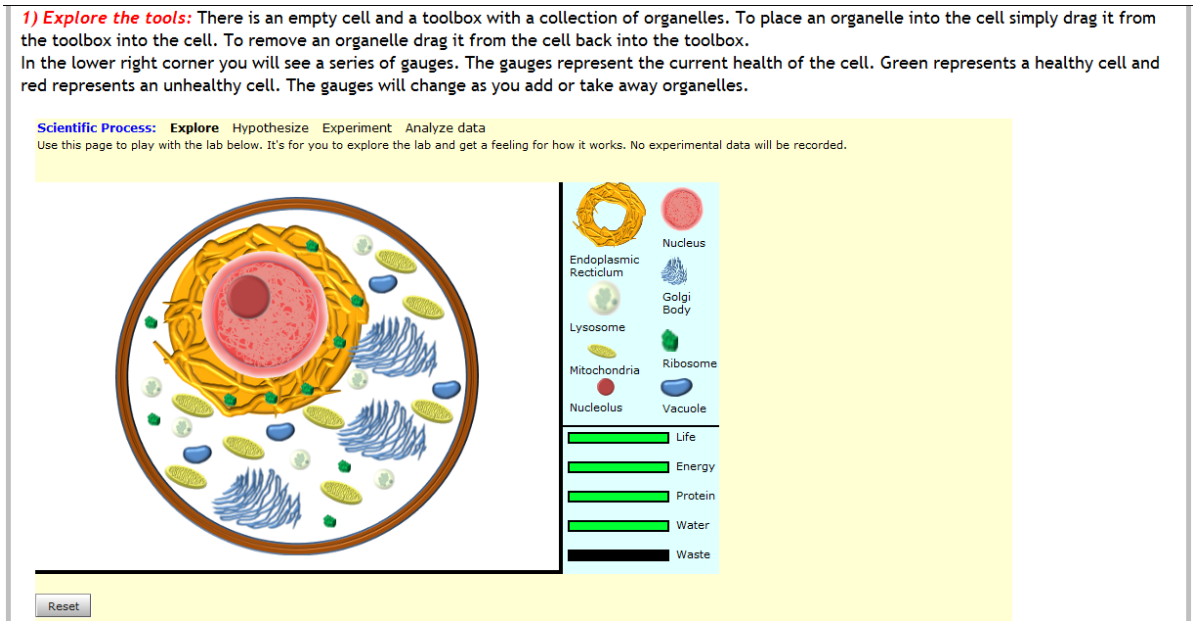
Scientific Process: **Explore** Hypothesize Experiment Analyze data

Use this page to play with the lab below. It's for you to explore the lab and get a feeling for how it works. No experimental data will be recorded.

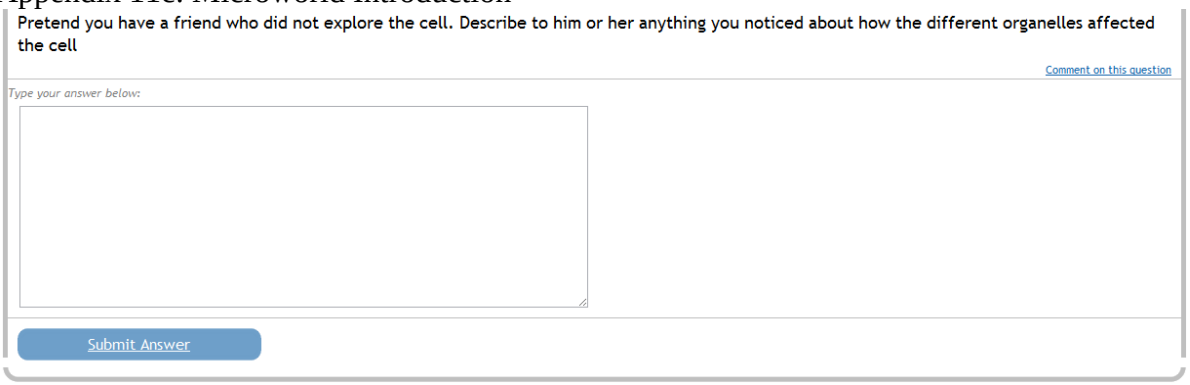


Reset

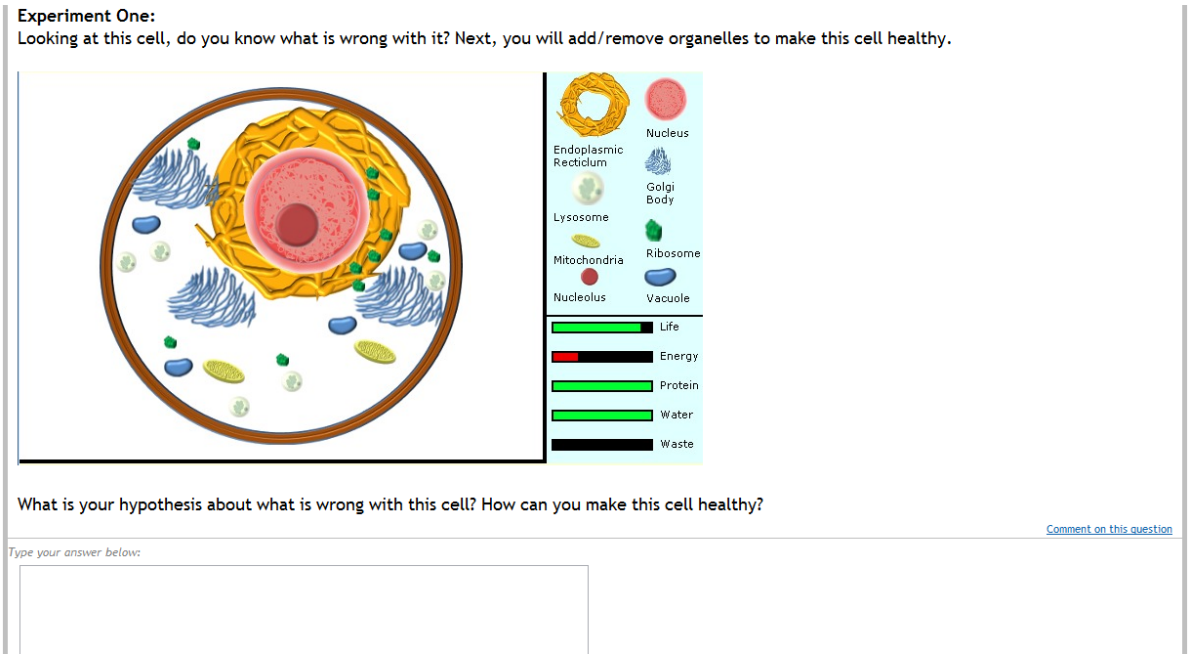
Appendix 11b: Microworld Introduction



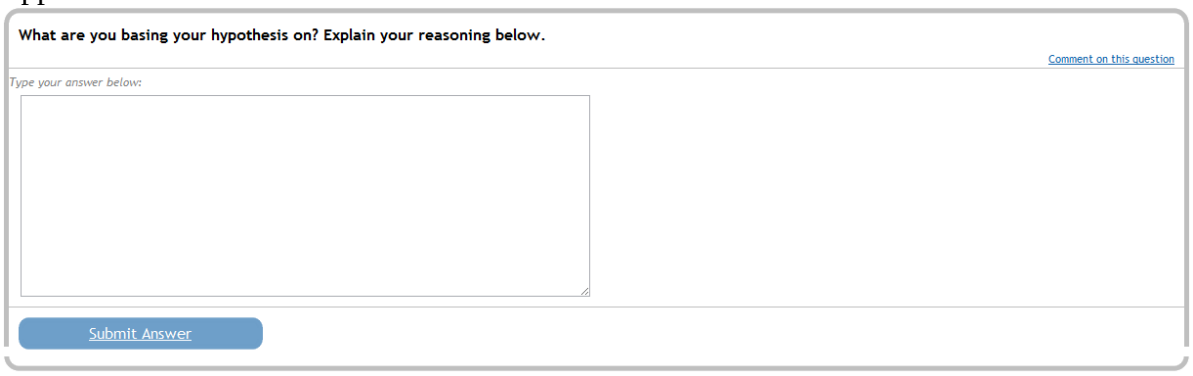
Appendix 11c: Microworld Introduction



Appendix 12a: Microworld Scenario One



Appendix 12b: Microworld Scenario One

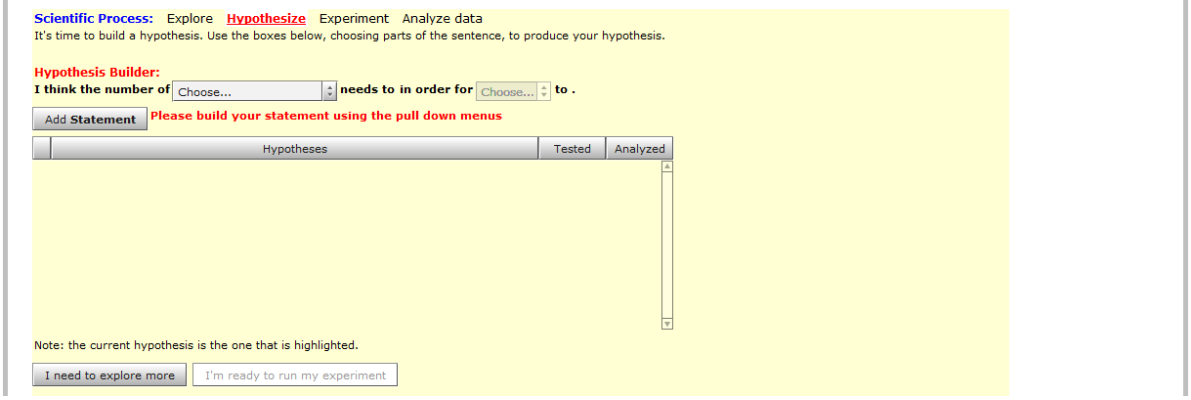


Appendix 13a: Hypothesis Widget

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

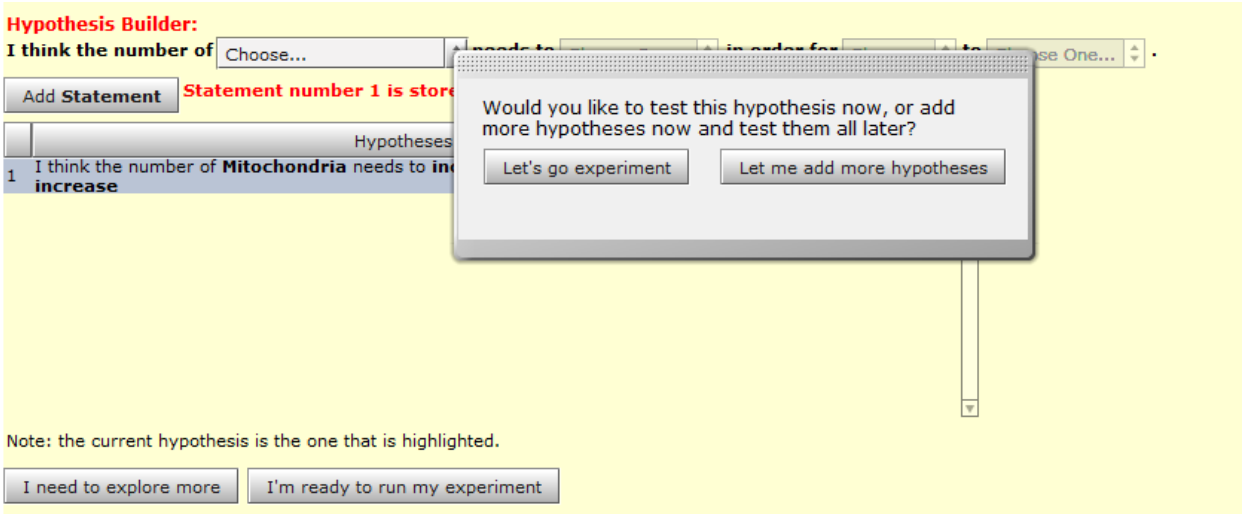
2. **Collect data to test your hypotheses:** Add or remove organelles and hit record when you wish to save data you plan on using as evidence.

3. **Remember to control for variables while collecting data:** You are trying to find out what is causing the problem with this cell. This may involve adding or removing many different types of organelles. When you want to test the effects of a specific organelle, remember to only add or remove one type of organelle at a time. That way when you look at the health gauges, and your data table, you know exactly what organelle caused that change.

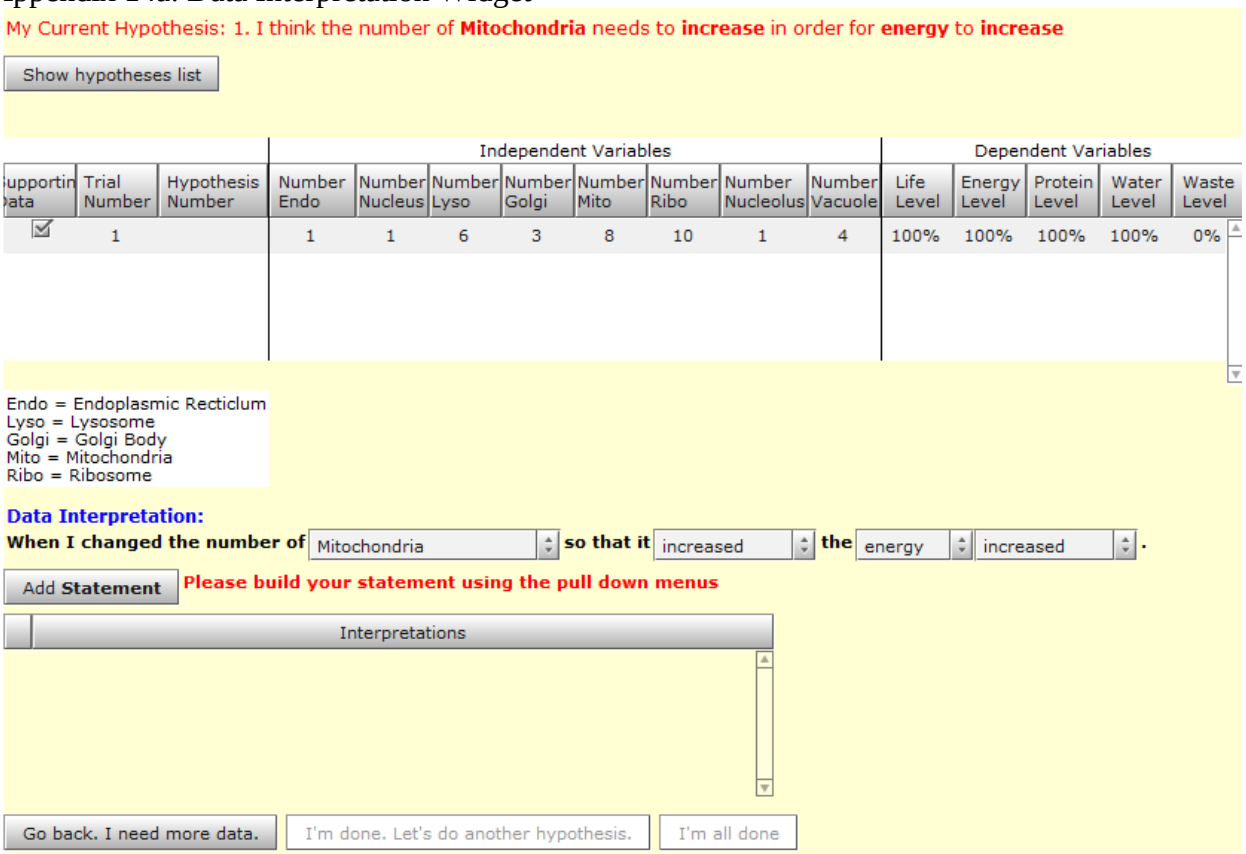


Appendix 13b: Hypothesis Widget

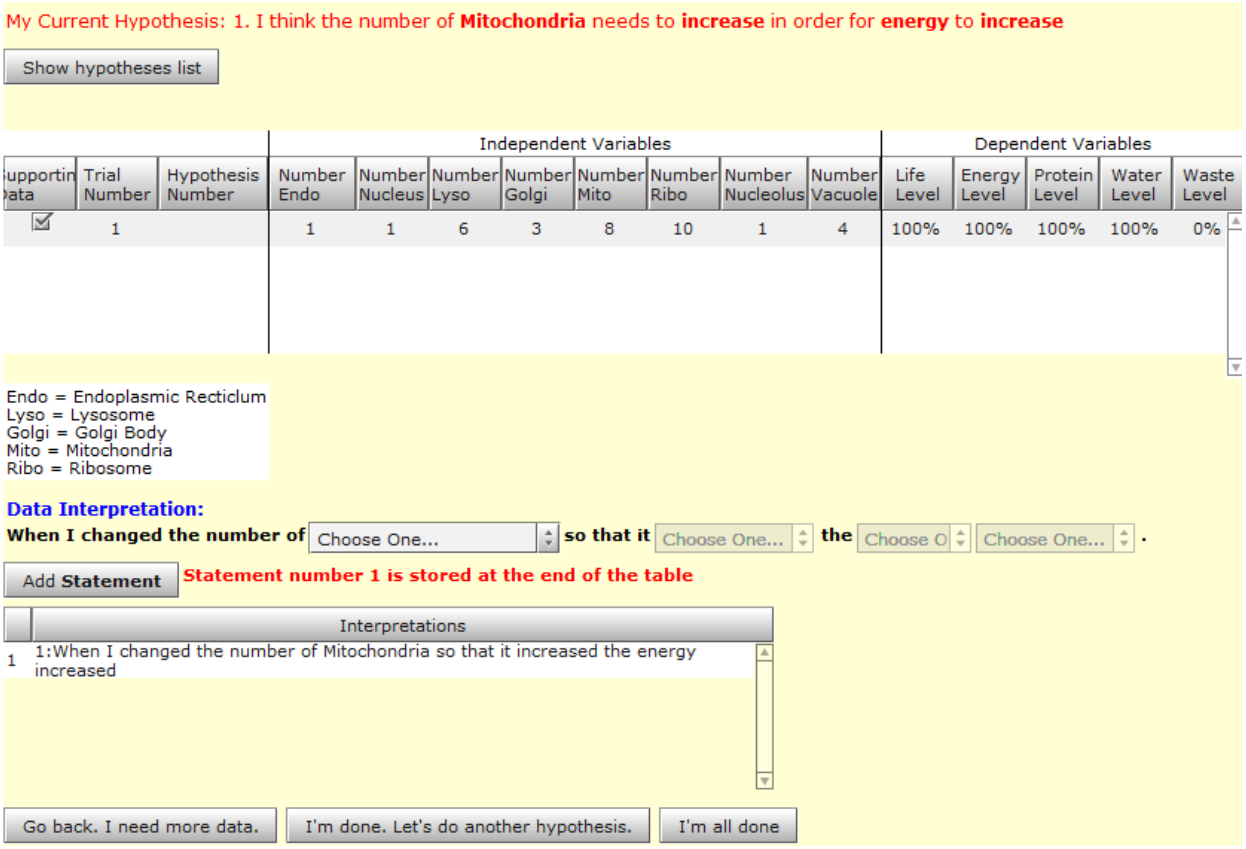
Appendix 13c: Hypothesis Widget



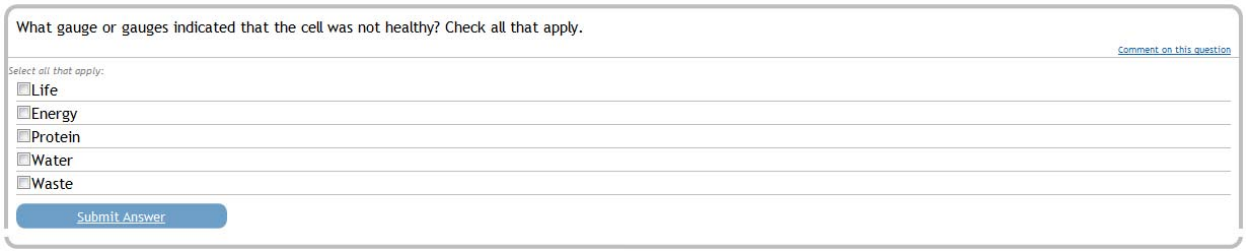
Appendix 14a: Data Interpretation Widget



Appendix 14b: Data Interpretation Widget

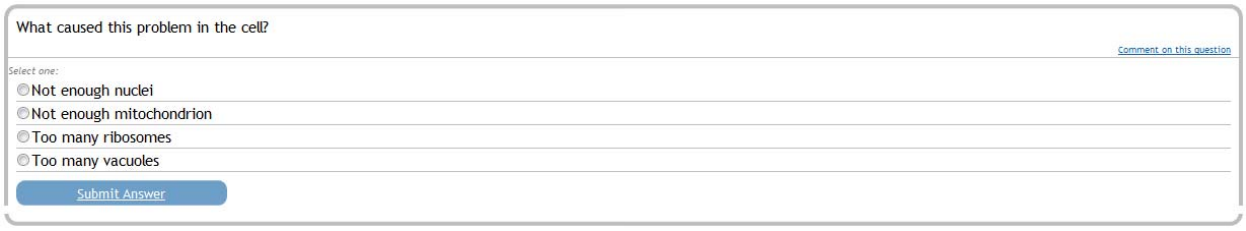


Appendix 15a: Microworld Scenario One Embedded Question

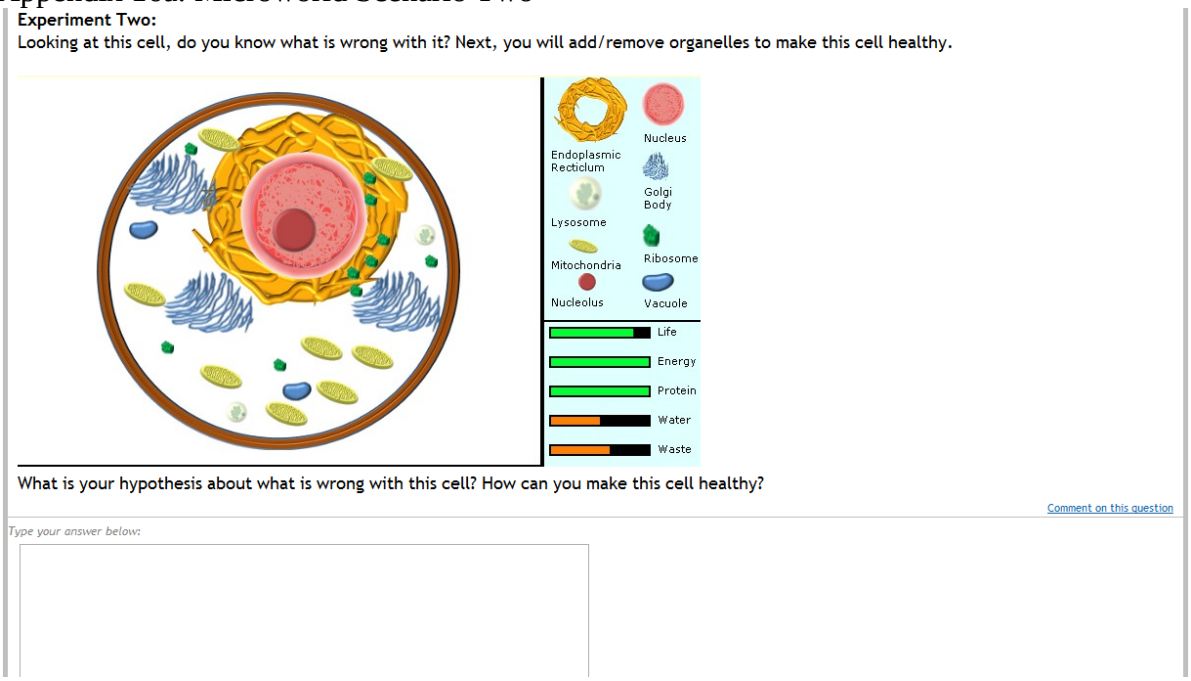


Appendix 15b: Microworld Scenario One Embedded Question

Appendix 15c: Microworld Scenario One Embedded Question

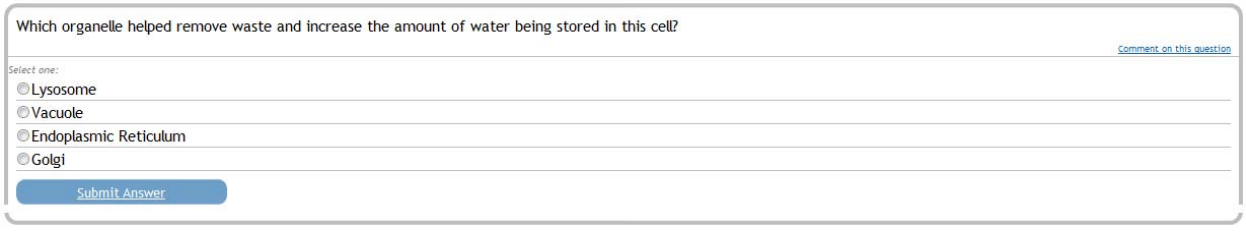


Appendix 16a: Microworld Scenario Two

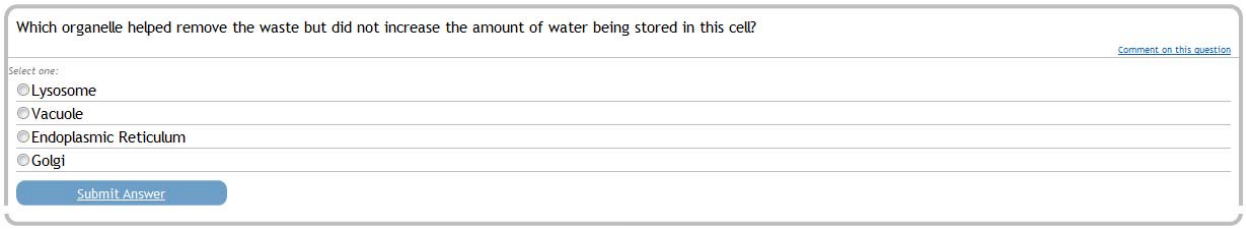


Appendix 16b: Microworld Scenario Two

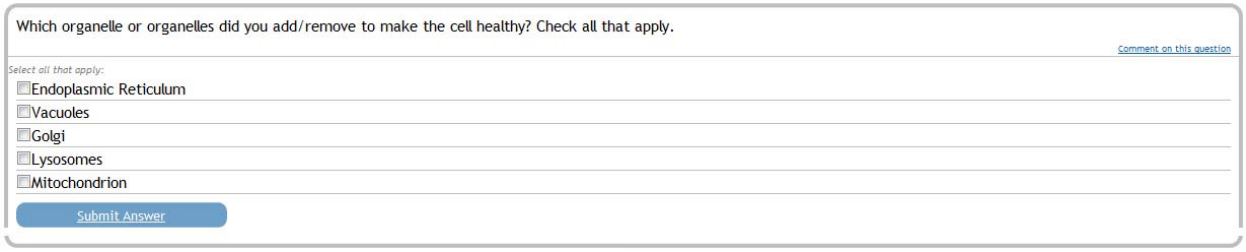
Appendix 17a: Microworld Scenario Two Embedded Question



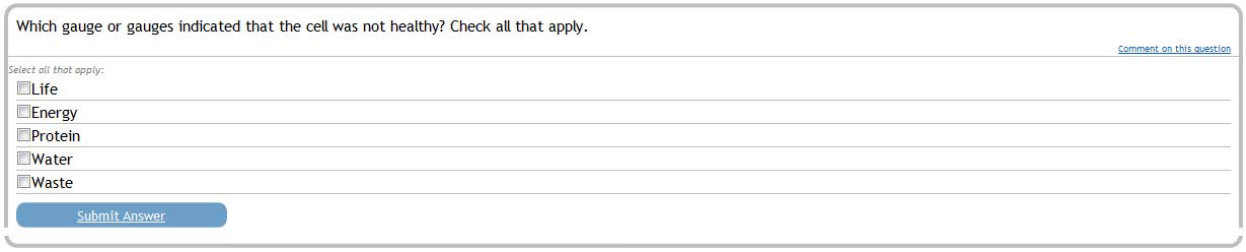
Appendix 17b: Microworld Scenario Two Embedded Question



Appendix 17c: Microworld Scenario Two Embedded Question



Appendix 17d: Microworld Scenario Two Embedded Question



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