

TEACHING BIOLOGY WITH MODEL ORGANISMS

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## **ABSTRACT**

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The purpose of this study is to identify and use model organisms that represent each of the kingdoms biologists use to classify organisms, while experiencing the process of science through guided inquiry. The model organisms will be the basis for studying the four high school life science core ideas as identified by the Next Generation Science Standards (NGSS): LS1-From molecules to organisms, LS2-Ecosystems, LS3- Heredity, and LS4- Biological Evolution. NGSS also have identified four categories of science and engineering practices which include developing and using models and planning and carrying out investigations. The living organisms will be utilized to increase student interest and knowledge within the discipline of Biology. Pre-test and posttest analysis utilizing student t-test analysis supported the hypothesis. This study shows increased student learning as a result of using living organisms as models for classification and working in an inquiry-based learning environment.

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## RATIONALE

The beginning of the school year brings a new group of students to Honors Biology that will be expected to acquire specific skills in order to become successful biological scientists. The students will need to use the scientific method, engage in inquiry-based science, write a formal lab report, use a microscope construct and interpret graphs, along with recognizing the names and uses for science equipment. The first chapter of virtually every Biology text book also introduces the study of biology, recognizing that it is the study of living organisms. The first unit in Honors Biology was called *The Study of Life*; however, it was composed of several “hands-on” experiments that used science equipment, collected data to make graphs, and followed cook-book like labs. The labs did not use living organisms; rather, the materials included M & M’s, paper towels, glow sticks, and eggs. To solve this problem, living organisms were identified as models for each kingdom, and labs designed to teach inquiry and science skills were developed with the living organisms. The end of the school year included the characteristically favorite unit in Honors Biology, comparative anatomy and classification. In this unit the students studied living organisms from three Kingdoms: Moneran, Protista, and Animalia. The students also had the opportunity to design and implement their own experiment, and dissect animals. The end of the year was a culmination of their study of Biology, and it utilized the students’ acquired skills that began with the first unit: *The Study of Life*. The development of this unit identified the student’s level of engagement with living organisms, the required benchmarks in classification and characteristics of organisms, and inquiry-based science learning.

## DEMOGRAPHICS

Forest Hills Public School District is in the suburbs of Grand Rapids Michigan. The communities of Ada and NE Grand Rapids primarily make up the school population, and there is a blend of many different professions in the area. The District serves just over 10,000 students with eleven elementary schools, three 7-8 middle schools, and three 9-12 high schools. The study was conducted at one of the three high schools, Forest Hills Eastern. Within Eastern High School, 83.4% of the population is white, 6.65% is Asian, 2.5% of the population is African American, and 7.45% is Hispanic, American Indian, Multiracial, and Refugees from around the world. 95% of our graduates pursue post-secondary education. The study was conducted at Forest Hills Eastern High School which has 9.3% of the students on free and reduced lunch programs.

The study was conducted with 2 classes of Honors Biology students. The students were all freshman, except for three accelerated eighth graders. In order to enroll in Honors Biology, the students must have their eighth grade science teacher initial the class choice. Students that do not sign-up for Honors Biology register for Biology. All freshmen are required to pass one year of Honors Biology or Biology. The course description for Honors Biology explains two differences between the two class choices: weighted grade scale and *Formal Lab Reports* for Honors Biology. Typically the students have all earned "A's" in eighth grade science because they are either natural academics (smart; good testing skills) or because they have a good work ethic. There were 57 students who signed the *Parent Consent and Student Assent Form* (Appendix 1). In this study, 79% of the students were white, the rest were Asian or Hispanic. All three high schools have agreed to the same weighted grading scale for Honors Biology: 45%

Labs & Projects, 45% Assessments (quizzes/tests) and 10% Daily work. All Honors Biology students are also required to complete at least one “*Formal Lab Report*” for each unit, however the specifics of the write-up is determined by the individual teachers.



## THEORETICAL FRAMEWORK

The typical biology textbook begins with the first chapter on the *Study of Life*, which is an introduction to biology and the methods of science. This chapter includes the characteristics of living organisms, the characteristics of science, and the scientific method. The first chapter is designed to introduce the year-long study of biology and the scientific method. The scientific method is generally taught as a linear, five step process. The steps of the scientific process according to *Glencoe Science Biology* book are the following: observation, hypothesis, design and conduct an experiment, record the data, and draw a conclusion. The problem is that the textbooks fail to convey the complexity and diversity of living organisms, the nonlinear complexity of inquiry science, and do not incorporate the Next Generation Science Standards. Science is about exploration and discovery with the key elements of the scientific method being (Dyer, 2014):

- Observations about particular natural patterns
- Questions about the causes/explanations for these patterns
- Hypotheses about the possible causes of the phenomenon or potential answer to a question
- Predictions that each hypothesis makes if it is supported
- An additional observation or experiment that could be done that would allow testing of this prediction

Over the course of teaching science at the middle school and high school levels for several years, the author's definition of inquiry-based science learning evolved from a heavy emphasis on "hands-on" labs and activities to a balance of "hands-on" and "minds-on" labs and

activities. The author presented at NSTA (National Science Teachers Association, 2001) a workshop entitled *"Inquiry: Just ADD in science"*. It was an acronym for Ask, Do, Discuss. The addition of questioning and analyzing to the hands-on activities and labs required the students to think about and apply their knowledge. Also over the years of teaching, there was clearly a push towards inquiry-based science learning. However, the amount of time required to actually implement inquiry-based labs presented the dilemma of what to keep and what needs to be dropped. At the same time that inquiry-based science learning was being urged, problem-based learning was promoted. The interdisciplinary approach to solving problems demonstrated a way in which to condense and realign the learning benchmarks. The result of interdisciplinary problem solving, a deeper understanding of inquiry-based science, and years of teaching Honors Biology allowed the author to identify an opportunity for the first unit in Honors Biology. The unit would integrate the specific skills required of Honors Biology students, the understanding of what Biology is all about, and classification of living organisms into one unit. The unit would utilize LIVING organisms to teach inquiry-based science. This first unit in Biology is the study of living organisms, so why wait until the end of the school year to study living organisms?

The scientific method traditionally taught in science classrooms gives students (and teachers) a false view of the way science works. The scientific process is not the step-by-step recipe illustrated in most textbooks. It is a messy, creative, demanding, and often unpredictable endeavor, defying any attempts to be easily packaged (King & Schwartz, 2014). The scientific method is interactive, not linear. The scientific method should be comprised of the same

activities and thinking processes as scientists who are seeking to expand human knowledge of the natural world (NRC, 2000).

The current focus of much work in science education reform is to bring more authentic science into classrooms. The work has encompassed conceptual scaffolds for scientific inquiry (Reiser et al, 2001), and problem-based environments in order to present learners with opportunities to engage in complex tasks (Reiser et al, 2000). Reformers are attempting to bring more of the practices of scientific inquiry into student learning activities (NRC, 1996). In order to achieve a classroom that practices scientific inquiry, an understanding of the term “inquiry” is required. According to the *National Science Education Standards* (NRC, 1999), the term is used in two different ways. First, it refers to the abilities students should develop to be able to design and conduct scientific investigations and the understandings they should gain about the nature of scientific inquiry. Second, it refers to the teaching and learning strategies that enable scientific concepts to be mastered through investigations. Similarly, science education needs to give students three kinds of scientific skills and understandings (NIH, 2005). First, students need to learn the principles and concepts of science. Second, students need to acquire the reasoning and procedural skills of scientists. Third, students need to understand the nature of science as a particular form of human endeavor.

Inquiry initially was defined as a type of “hands-on” learning, with the “hands-on” referring to students handling equipment to follow a prescribed procedure. Often the science process skills such as observing, questioning, and predicting were not a component of the “hands-on” labs. Early in the author’s teaching career there were many “hands-on” experiments in which students followed the procedures and recorded results. Support for

“hands-on” instruction is not new. In the seventies, it was recommended that “the use of active methods which give broad scope to the spontaneous research of the child or adolescent and require that every new truth to be learned be rediscovered or at least reconstructed by the student, and not simply imparted to him” (Piaget, 1976). In the 1960’s it was suggested that teachers should present science as inquiry and that students should use inquiry to learn science subject matter (Schwab, 1962). In the years that have passed, how many children have spent a part of their science classes involved in experiments that were “hands-on” but not “minds-on”? Inquiry is both physical and mental. It is doing and making sense of that doing (Gallagher, 2007).

Constructivism is a view of learning based on a belief that knowledge isn’t a thing that can be simply given by the teacher at the front of the room to students in their desks. Rather, knowledge is constructed by learners through an active, mental process of development; learners are the builders and creators of meaning and knowledge. Constructivism draws on the developmental work of Piaget (1977) and Kelly (1991). Twomey Fosnot (1989) defines constructivism by reference to four principles: learning, in an important way, depends on what we already know; new ideas occur as we adapt and change our old ideas; learning involves inventing ideas rather than mechanically accumulating facts; meaningful learning occurs through rethinking old ideas and coming to new conclusions about new ideas which conflict with our old ideas. A productive, constructivists’ classroom, then, consists of learner-centered, active instruction. In such a classroom, the teacher provides students with experiences that allow them to hypothesize, predict, manipulate objects, pose questions, research, investigate, imagine, and invent. The teacher’s role is to facilitate this process.

The National Research Council (NRC, 2000) has identified the essential features of classroom inquiry as a classroom where there are five learner objectives. The first identifies learners that are engaged in scientifically oriented questions. Scientifically oriented questions center on objects, organisms, and events in the natural world; they connect to the science concepts described in the content standards. The second identifies learners that give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions. As the *Standards* note, science distinguishes itself from other ways of knowing through use of empirical evidence as the basis for explanations about how the natural world works. The third identifies learners that formulate explanations from evidence to address scientifically oriented questions. This aspect of inquiry emphasizes the path from evidence to explanation rather than the criteria for and characteristics of the evidence. The fourth essential feature identifies learners that evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding. Evaluation, and possible elimination or revision of explanations, is one feature that distinguishes scientific from other forms of inquiry and subsequent explanations. The final essential feature of classroom inquiry identifies learners that communicate and justify their proposed explanations. Scientists communicate their explanations in such a way that their results can be reproduced. Taken as a whole, these essential features introduce students to many important aspects of science while helping them develop a clearer and deeper knowledge of specific science concepts and processes.

Inquiry-based science will have these five essential features; however, there are variations within each of the five essential features. The NRC recognized the spectrum of variations on a scale of more to less in the following:

- **MORE..... Amount of Learner Self-Direction..... LESS**
- **LESS..... Amount of Direction from Teacher or Material..... MORE**

The NRC labeled inquiries as “full” or “partial”. The labels refer to the proportion of the **MORE... LESS** sequence of learning experiences that is inquiry-based. The early “hands-on” experiments by the author were a partial inquiry, because they did not engage students with a question but began by assigning an experiment. In order to move to full inquiry, students need to explore and develop their own questions or explanations, and have more opportunities for self-direction. Also to implement full inquiry, the teacher decreases the amount of direction and allows the students more self-direction. The **MORE** continuums were identified by the NRC (1996) for each of the five essential features. Table 1 summarizes the five essential features and the learner variation that will exhibit the highest (more) level of full inquiry.

**Table 1:** Essential Features of Classroom Inquiry and Learner Variation

Essential Feature Of Classroom Inquiry	<b>MORE</b> Variation for Learner
Learners are engaged in scientifically oriented questions.	Learner poses a question.
Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.	Learner determines what constitutes evidence and collects it.
Learners formulate explanations from evidence to address scientifically oriented questions.	Learner formulates explanation after summarizing evidence.
Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.	Learner independently examines other resources and forms the links to explanations.
Learners communicate and justify their proposed explanations.	Learner forms reasonable and logical argument to communicate explanations.

The degree to which teachers structure what students do is sometimes referred to as “guided” versus “open” inquiry. The Van Andel Education Institute (VAEI), located in Grand Rapids, Michigan, has a mission to prepare the scientists and leaders of the future by promoting and strengthening science education. One of several programs they offer is professional development for teachers through the science academy at VAEI. The purpose is to enable teachers to more effectively engage their students in inquiry-driven science education (Triezenberg, 2014). According to the Van Andel Education Institute, there are five levels of inquiry-based science ranging from “messaging about” to “open-inquiry”. The VAEI Science Academy has developed several products that promote and support the teaching and learning of science as the integration of both knowing science and doing science. The products all feature scientific inquiry, and are available for purchase. VAEI has two products that expand the continuum and explain the scaffold for engaging students in scientific inquiry from “messaging around” to “open-inquiry”. The QPOE<sub>2</sub> Investigation Organizer Step book and the QPOE<sub>2</sub> Inquiry Framework App are graphic organizers designed to guide students in the process of thinking and acting like scientists. QPOE<sub>2</sub> is a mnemonic for each component of scientific inquiry; **Q**uestion, **P**rediction, **O**bservation, **E**xplanation, and **E**valuation. Within the QPOE<sub>2</sub> framework, they describe the continuum of inquiry levels. “Messing about” is described as an opportunity for students to build needed knowledge, skills, and experience through direct exploration, prior to an inquiry learning experience. The first inquiry level is called “Confirmation” and is characterized as students confirming a principle through an investigation where the results are known in advance. Many “hands-on” activities and labs are at the confirmation level of inquiry. The second level of inquiry is called “Structured” and is

characterized as students investigating a teacher-presented question through a prescribed procedure. Step two is also an example of many “hands-on” experiments. The third level of inquiry is called “Guided”; this step allows students to investigate a teacher-presented question using their own design and selected procedure. The final step, the end of this continuum, is called “Open” inquiry. In “Open” inquiry students investigate questions that are student formulated through student designed/selected procedure. VAEI notes that students will often experience all levels of inquiry during a single unit. Lower level inquiry is used to build the knowledge and experience students will need to be successful at the more advanced levels. Appendix 3: Levels of Inquiry Continuum lists what the students are provided with, and explains the role of the student at each inquiry level. The labs created for this study were designed to start students at a beginner level of inquiry called confirmation and build to a skilled level of inquiry called open inquiry. The “messaging about” allows students to build needed prior knowledge, skills, and experience through direct exploration. This unit utilized several “messaging about” explorations as a way to brainstorm and ask questions. Those questions generated would provide the students with several options in order to design their own “open” inquiry lab.

Using inquiry in the classroom coincides with Piaget’s Theory of Cognition that states that learners build and tweak their knowledge based on experiences that they have with the physical world. Science teachers must give students opportunities to interact with the physical world in the classroom setting in order to get them to build and refine their knowledge (Magee & Barman, 2009). If students never get the opportunity to interact with living organisms and manipulate variables through inquiry and experimentation, educators can expect that they will



not overcome misconceptions, build on prior knowledge, or increase science skills. This kind of engagement helps students understand how science works as a process rather than simply a collection of facts (Settlage & Southerland, 2007).

The author has been committed to building an inquiry-based science classroom since the start of her second career in science education. There are two additional Biology teachers at Forest Hills Eastern High School. These teachers attribute Honors Biology students' success on the final exams to the fact that they are "Honors" students, and not on the increased amount of inquiry-based learning experiences the Honors Biology students have. There are several studies illustrating the benefits and increased knowledge students gain through hands-on, laboratory, and inquiry activities. These "hands-on" and "minds-on" experiences have a positive effect on student achievement. According to Stohr-Hunt (1996) students that have hands-on experiences in science at least once a week score significantly higher on standardized tests compared to students that have hands-on experiences less frequently. Freedman (1997) concluded in his study of hands on laboratory experiences versus no laboratory experiences in a large, urban, inner city school that students receiving laboratory experiences once per week for 36 weeks scored significantly higher on midterm and final posttests than their no laboratory experiences counter parts. Taraban et al (2007) found labs significantly increased student content knowledge and process skills when compared to traditional lecture teaching; additionally, active learning provided a significant advantage in factual recall and process skills. This study of 408 high school students from rural and urban settings with teachers of varying degrees of experience found that for factual recall there was a significant 6.89% mean accuracy advantage and for process skills questions a significant 8.30% advantage for active learning

instruction over traditional instruction. Also students with disabilities that were instructed in a hands-on approach had significantly higher achievement when compared to students taught in a more traditional textbook oriented approach (McCarthy, 2005).

It is said that inquiry-based science learning is effective because it allows students to work together, to 'play' with objects, and to manipulate the surroundings (Satterthwait, 2010). Students learn cooperation, accountability, reflection, knowledge, and the nature of science. They learn how to make hypotheses, infer, and analyze data (Flick, 1993). It is important that students experience hands-on learning because it demonstrates that the conceptual knowledge that exists has come from experiments and interpretation of the data from those experiments (Taraban et al, 2007)

The unit, on which the study reported here is based, not only involves students in inquiry-based science, but also addresses both *A Framework for K-12 Science Education* (NRC 2012), and the *Next Generation of Science Standards* (NGSS Lead States 2013). Students generate questions, plan and carry out their own investigations, collect data, determine independent and dependent variables, and analyze and share their results (Bourdeau 2004). Students also experience the scaffolding of problem-based learning and inquiry learning which allows them to learn content knowledge, epistemic practices, and soft skills such as collaboration and self-directed learning (Hmelo-Silver et al, 2007).

The Michigan Curriculum Framework requires that secondary students understand and know specific science content standards. The following 'Big Ideas and Main Ideas' are the core curriculum content standards for high school from Standard III.2 *Organization of Living Things*. Forest Hills Public schools identified these benchmarks to be taught in Unit 1: *Biology, The*

*Study of Life*, for all Biology and Honors Biology students. This thesis unit was developed to teach the following “Big ideas” and “Main ideas” from the Michigan benchmarks, and includes the following classification benchmark: classify major groups of organisms to the kingdom level.

**BIG IDEAS:**

1. All living things share the characteristics of life.
2. Science is a process based on inquiry that seeks to develop explanations.
3. Biologists use specific methods and tools when conducting research.

**MAIN IDEAS:**

- B1.1f* Predict what would happen if the variables, methods, or timing of an investigation were changed.
- B1.1g* Use empirical evidence to explain and critique the reasoning used to draw a scientific conclusion or explanation.
- B1.1h* Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables.
- B1.1i* Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate.
- B1.2h* Describe the distinctions between scientific theories, laws, hypotheses, and observations.
- B1.2i* Explain the progression of ideas and explanations that lead to science theories that are part of the current scientific consensus or core knowledge.
- B1.2j* Apply science principles or scientific data to anticipate effects of technological design decisions.

*B1.2k* Analyze how science and society interact from a historical, political, economic, or social perspective.

The Next Generation Science Standards (NGSS, 2013) require that students in high school life sciences understand key concepts that are built upon their science understanding of disciplinary core ideas, science and engineering practices, and crosscutting concepts. The science and engineering practices are further divided into three categories; *Developing and Using Models, Planning and Carrying out Investigations, and Constructing Explanations and Designing Solutions*. The focus of the framework by NGSS has identified these three dimensions as key goals, and by identifying *Scientific and Engineering Practices*, has identified problem-based learning and inquiry-based learning as essential goals. The Next Generation Science Standards (NGSS) is based on *A Framework for K-12 Science Education* released by the National Research Council. In the December 2011 issue of *Science Scope*, Rodger Bybee provided an overview of the Scientific and Engineering practices and showed how they are a refinement and further articulation of what it means to do scientific inquiry in the science classroom. The *Framework* identifies eight scientific and engineering practices that should be used in science classrooms. These practices reflect the multiple ways in which scientists explore and understand the world and the multiple ways in which engineers solve problems. These practices include:

- Asking questions (for science) and defining problems (for engineering)
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data

- Using mathematics, information, and computer technology, and computational thinking
- Constructing explanations (for science) and designing solutions (for engineering)
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

This thesis study is based on using model organisms for teaching Biology, and was initially intended to primarily address the scientific practice identified above: developing and using models. The focus became developing inquiry-based scientific models to explain and predict phenomena and what it means for classroom teaching. There are many definitions for models; for example, all models are external representations of mental concepts (Krajcik and Merritt, 2012). Models provide scientists and engineers with tools for thinking, to visualize and make sense of phenomena and experience, or to develop possible solutions to design problems (NRC 2011). Models can include diagrams, three-dimensional physical structures, computer simulations, mathematical formulations, and analogies. The focus in this unit is narrower, defining a model as a living organism that is the representative for a specific Kingdom. One example of a model in this unit is studying *Physarum polycephalum*, or slime mold. The slime mold is used as a model for the Fungi Kingdom in order to understand the characteristics of the organisms classified in that kingdom.

It's critical that a model be consistent with the evidence that exists, and that different models are appropriate in different situations depending on what is being explained, and the level of explanation. Critically, if the model cannot account for the evidence, then the model should be abandoned or modified (Schwarz et al. 2009). The use of living model organisms is expected to engage students in what it means to do science, and "doing science" drives

scientific work and thinking. According to *Framework*, it is important for students to construct models that explain phenomena, show how their models are consistent with their evidence, and explain the limitations of those models. For example, students carrying out investigations using slime mold should be able to hypothesize various characteristics of the Fungi kingdom, while recognizing that not every organism in the Fungi kingdom reproduces and responds to stimuli as do slime molds. The ultimate goal for students investigating these models at the beginning of their Biology course is to be able to build on those foundations, as encountered in the curriculum, the more complex characteristics of living organisms. For example, when learning how living organisms reproduce, they can identify with each model organism from each kingdom. The modeling practices of inquiry-based science should develop students who view exploring science models as an effective method of inquiry. Using models can lead students to deeper understandings of scientific concepts, practices of science, the nature of science, and the ability to explain phenomena and solve problems (Khan 2011; Louca, Zacharia, and Constantinou 2011). *Framework* emphasized the importance of students developing and using models as a central learning outcome. *NGSS* identifies a prominent role for students developing and using models to engage in engineering practice.

Models can also be used as a verb in science education; a science teacher *models* the scientific method and inquiry-based science. In this unit, a scaffold approach to the inquiry method introduced the steps one lab at a time. There were six labs in the unit; the first labs were structured labs where the students investigate a teacher-presented question through a prescribed procedure. The students were provided the question and the procedure to follow in order to carry out the investigation, and they generated explanations that were supported with

evidence and reasoning. The next labs were guided in that the students were provided the question, and they designed and carried out an investigation to test the teacher generated question. The final lab was an open inquiry. The students generated a question to answer, and designed and carried out the investigation to test the question. The structured labs allowed students to build the knowledge and experience they needed to be more successful at the more advanced levels of inquiry.

## RESEARCH AND DESIGN

The research at Michigan State University during the summer session 2013 was to: 1) identify one model organism from each kingdom of biological classification in order to provide students with an engaging hands-on biological experience, and 2) build activities and labs that would provide the foundation for the process of science known as inquiry-based. It was decided that studied activities would include the elements of inquiry-based learning and would follow Van Andel's QPOE<sub>2</sub> design and *Levels of Inquiry Continuum* (Appendix 3), including the elements of "messing around", "brainstorming", and "knowledge probe". Additionally, the living organism models would be based on scientific and engineering practices; *Developing and Using Models* identified by NGSS.

### Plantae Kingdom

Originally, *Brassica rapa* (Wisconsin Fast Plants) was to be used as the model organism for the Plantae Kingdom. These plants can provide excellent investigations for the Ecology unit and Genetics unit, but are expensive. Therefore, to introduce students to the Plantae Kingdom and inquiry-based investigative experiments, seed germination became the activity and inexpensive radish and pea seeds were used. This decision enabled each student to have their own seeds in order to complete the three scaffolding inquiry labs (Parts 1, 3, 4) that comprise Lab 1: SCIENTIFIC METHOD- SEED GERMINATION (Appendix 4). Lab 1 was modified from several labs that I have used over several years.

### Fungi Kingdom

The labs related to the Fungi Kingdom were described in *Inquiry and Learning* (Layman, 1996) which used slime mold, *Physarum Polycephalum* to introduce biology students to



observation and experiment. In the process of learning to grow the mold, students began making general observations of the characteristics of the living organism. Students were asked to brainstorm questions about slime mold, based on their observations. After brainstorming, students narrowed the list of questions to those that can be answered within a day. Lab 2 (Appendix 5) became the Fungi Kingdom model using *Physarum Polycephalum*. This lab was designed to ask a structured inquiry question that required a knowledge probe. The students found that *Physarum polycephalum* utilizes oatmeal as food, requires some moisture, and have an ideal growth temperature.

### **Protista Kingdom**

*Tetrahymena thermophila* is a genus of common, freshwater, ciliated protozoa with a very wide geographical range. *Tetrahymena* are small, and require a microscope to observe. They grow quickly, withstand a broad range of pH, temperature, nutrient availability and oxygen concentration. *Tetrahymena* are model organisms for studying basic research questions (Carolina Biological, 2004) in areas such as genetics, protein phosphorylation, aging, and biomedical research. The student instructions from Carolina Biological background information explains several landmark discoveries made using *Tetrahymena*. The student introduction ended with the following challenge: “Use your imagination and you might come up with something no one else has thought of before you!” The student instructions also gave directions for making a wet mount, and directions were given for using a microscope. This provided a very engaging experience for the students. In the past, the students would learn how to make wet mounts and use the microscope with the letter “e”. They were considerably more excited to see a living organism, and cautious to not harm their critters. The Carolina

student guide was used in conjunction with *Lab 3: SCIENTIFIC METHOD- Tetrahymena* (Appendix 6). Several students were intrigued and subsequently followed up by testing the following suggested activity by Carolina student guide:

Use a toothpick and petroleum jelly to draw three sides of a rectangle on a microscope slide. Place a couple of drops of *Tetrahymena* within this open box. Gently lower a coverslip on top and press gently to seal the three edges. Observe the behaviors of *Tetrahymena* for the next few minutes.

### **Animalia Kingdom**

Based on various presentations during the MSU summer session (2013), pill bugs and daphnia (*Daphnia magna*) were chosen as the model organisms for the Animalia kingdom. Lab 4: SCIENTIFIC METHOD- Pill and Sow bugs (Appendix 7) was developed with two parts: a “messaging around” segment of inquiry that would allow students to build needed prior knowledge and skills through their experience with pill bugs, and an “open inquiry” that would allow students to investigate a question that was student formulated. The *Terrestrial Isopods Care Sheet* (Carolina) was downloaded onto the iPads in the drop box app for the students to use for their knowledge probe. Each student was provided a plastic collection jar, and divided chambered plates with lids for experimenting. The students had an investment in the organism, because the students found them.

*Daphnia magna* became the focus of study for Lab 6: SCIENTIFIC METHOD- *Daphnia*. The students worked in groups of two or three and completed an “open inquiry” and followed the *Honors Biology: Writing Formal Lab Reports* (Appendix 10). The students completed their work on the iPads. The student instructions from *The Effect of Drugs* (The Science Source) and

handouts from Van Andel Education Institute were provided to students. The students presented their data using the iPad and the Apple TV to their peers.

### **Monera Kingdom**

*Serratia marcescens* are prokaryotes that are gram negative, bacillus (rod shaped) bacteria commonly found in soil and water habitats. They produce a pink/red tripyrrole pigment called prodigiosin in response to temperature. The *Serratia* are a model for changes in gene expression (Heidemann, 2011). *Serratia* also are organisms that produce prodigiosin in response to temperature, and respond to cell density (Hejazi, 1997). During the summer 2011 Biochemistry and Cell Biology for Teachers course at MSU, the effect of temperature and population density on prodigiosin production of *Serratia marcescens* was investigated. The characteristic color changes are easily observable by the eye, and data can be quantified by using a spectrophotometer. The students do not have access to a spectrophotometer, so they downloaded the Image J software which is free at <http://rsb.info.nih.gov/ij/download.html>.

## IMPLEMENTATION

To begin the school year, all my classes spent the first week in “Keeley Kamp”. This is comprised of several team building activities, games, and setting goals. An assignment for my two sections of Honors Biology was to complete and return the consent form (Appendix 1). The objective for this assignment was to present information about the thesis project, answer questions and have the students share the information with their parents/guardians. The principal stopped in each day to collect the consent forms which were returned in sealed envelopes. Open House was on the Monday of the second week of school, so any students that had not turned in their forms had their parents turn them into the office during Open House.

Unit 1: *The Study of Life* began the second week of the school year and took three weeks to complete. Table 2 is an overview of the daily activities in the unit, and identifies the kingdom of study (\*) for each model organism.

**Table 2:** Summary Time Table of Teaching Biology with Model Organisms

<b>Day</b>	<b>Activities/*Kingdom</b>	<b>Objective</b>
<b>1</b>	Unit Pretest/ Living vs. Nonliving Activity	Pre-test for stats.
<b>2</b>	Discuss HOG RACES/ Lab 1, Part 1: Seed Germination <b>*Plantae</b>	Characteristics of living organisms.
<b>3</b>	Discuss iPads: Knowledge Probe, QPOE <sub>2</sub> / Lab 2: Slime Mold <b>*Fungi</b>	iPad rules, knowledge probe and QPOE <sub>2</sub> .
<b>4</b>	Lab 1, Part 2: Brainstorming Seed Germination/ Lab 1, Part 3: Miracle Gro & Seed Germination	Brainstorming control experiment.
<b>5</b>	Lab 3, Part 1: Messing Around with Tetrahymena <b>*Protista</b>	Observations of Tetrahymena.
<b>6</b>	Discuss Formal Lab Write-up/ Lab 1, Part 4: Open Inquiry Seed Germination/ Lab 3, Part 2: Brainstorming Tetrahymena	Formal Lab Reports. Open Inquiry.
<b>7</b>	Lab 4, Part 1: Messing Around with Pill bugs <b>*Animalia</b>	Characteristics of Pill bugs.
<b>8</b>	Lab 5, Part 1: Knowledge Probe on <i>Serratia marcescens</i> (Bacteria) <b>*Monera</b> Lab 5, Part 2: Design and Set-up Temperature & <i>Serratia marcescens</i>	Design open-inquiry lab.

**Table 2 (cont'd)**

<b>9</b>	Lab 4, Part 2: Open inquiry Pill bugs	Complete inquiry lab.
<b>10</b>	Lab 6, Part 1: Messing around with Daphnia/ Knowledge Probe on Daphnia, Report using Keynote on iPads	Characteristics of Daphnia.
<b>11</b>	Lab 6, Part 2: Effect of Drugs on Daphnia	Inquiry Lab
<b>12</b>	Lab 6, Part 2: 2 <sup>nd</sup> test of Effect of Drugs on Daphnia	Inquiry Lab
<b>13</b>	Presentations using Keynote on Effect of Drugs on Daphnia	Presentations
<b>14</b>	Review Unit 1	Summary
<b>15</b>	Unit Post-test	Assessment

To begin the first unit of Honors Biology, students took the pre-test (Appendix 2) after the consent forms were collected. They were allowed 35 minutes to complete the pretest; for most of the students that was ample time. For the over achievers, it prevented them from writing for quantity rather than quality! Most students attempted an answer for all questions; I asked that they at least complete the graph and multiple choice questions. We then went outside to complete the *Living/Nonliving Activity* (Appendix 9). The school campus has a *Native Restoration Site*, a Michigan native plant garden. The *Native Restoration Site* is right outside my classroom, and the students have been involved with the development and maintenance of this prairie during seventh and eighth grade at Forest Hills Eastern middle school. My honors Biology classes received a \$1,000 grant each year from GOUNDSWELL to implement studies in the Native Restoration Site as well as the woods and pond on our school property. Students began this activity begins on their own, listing as many living organisms and nonliving things that they see or know they could find in that ecosystem. They were also asked to list the characteristics that they used to list living organisms. After they had a chance to start their list, they partner and share. They were encouraged to continue to add to their lists. After a few minutes with a partner, the partners paired and worked together as a foursome. The

homework was to have at least eight characteristics that classify an organism as living. Day two began with the list of characteristics of living organisms, known in Honors Biology as *HOG RACES*. "HOG RACES" is a mnemonic for the eight characteristics of living organisms, as explained in our Biology textbook (Glencoe Science):

1. Maintains **Homeostasis**
2. Displays **Organization**
3. **Grows** and develops
4. **Reproduces**
5. **Aadaptations** evolve over time
6. Made of one or more **Cells**
7. Requires **Energy**
8. Responds to **Stimuli**

The students highlighted the characteristics on their list that match hog races, and those that do not match were added to the list in RED pen. The red pen introduced them to the self-correcting that they complete on all of their work. Hog races are referred to throughout the year, and were the outline for all of Biology.

Lab 1: SCIENTIFIC METHOD-SEED GERMINATION (Appendix 4) began with part one, a structured inquiry experience in which the students investigated a teacher-presented question through a prescribed procedure. It had a bit of problem-based application by challenging the students to have the seeds germinated with the minimum number of requirements. Many students "lost" the challenge because they hypothesized that the seed needed sunlight, soil, and food/nutrients to germinate. Each student set up their own experiment, and they were

really excited about having their own seeds. The students collected data for up to three days, often all seeds germinated within 48 hours. After the students determined that the requirement for germination was water, the class discussed abiotic and biotic factors in an ecosystem. An understanding of abiotic/biotic was required background knowledge to begin Part 2: Brainstorming. The *brainstorming* was to identify a question they could test for Part 4: Open Inquiry, and also identify sources of controlled variables. This first lab was designed to scaffold inquiry by completing Part 3: Designing a Controlled Experiment, which was another structured inquiry lab. The purpose of Part 3 was to teach parameters of “doing science”: identify controls, constants, independent and dependent variables, number of trials, working with a group, making a graph, and observing inquiry-based science being modeled. In Part 3, students are directed to hang the baggies on a cabinet to save counter space in the lab.

Lab 1: Part 4: Designing an Open Inquiry Experiment began the third week of school. The students generated many ideas during the Part 2: Brainstorming activity and were allowed to share their top choice for their own experiment on a class Google doc. This helped them to identify a potential partner or partners to complete Part 4. They were introduced to the *Formal Lab Report* (Appendix 10) when Part 4 began, and this would be the first *Formal Lab Report* for Honors Biology. The weighted grade (45% Labs) that is required of all three Forest Hills High School Honor Biology classes makes these *Formal Lab Reports* an important part of their experience. In addition, the students needed to follow directions, write in complete sentences, and use the correct format to complete the lab. The students designed and carried out their investigations on a variety of parameters. Some students worked alone, some with a partner, some with a trio. However every student was required to type their own *Formal Lab Report*.

Part 1 and 3 were based on radish seeds; however they were given pea seeds for Part 4. The following is a list of tested parameters:

**Table 3:** List of parameters students tested with pea seeds

Types of Soil	Types of water
Temperature	Salinity
pH	Pre-soak seeds vs. Not Pre-soaked
Light Color	Amount of Light
Solid vs. Liquid fertilizer	Miracle-Gro vs. Store brand
Frost	Amount of Air
Seed Crowding	Placement of seeds(“upside down”)
Type of paper towel for germination	Amount of water

Lab 2: SCIENTIFIC METHOD- *Phyysarum polycephalum* began the day after Part 1 of Lab 1. *Phyysarum polycephalum*, a slime mold was the model organism for Fungi Kingdom. This lab was designed to introduce the students to the class set of iPads in the classroom, and the Knowledge Probe (Introduction) requirement on a *Formal Lab Report*. The Knowledge Probe (QPOE<sub>2</sub>) is defined as the process of thinking about what the student researcher or others already know about the topic. The purpose of the Knowledge Probe is to activate and identify personal and scientific prior knowledge and helps to bring to the forefront related scientific vocabulary words, concepts, and theories. The class set of iPads have the QPOE<sub>2</sub> app and it prompts students for the knowledge probe by asking: What do you already know about the question or topic? What is known by others? The QPOE<sub>2</sub> evaluation of the knowledge probe asks: Are at least four (4) “knowns” listed? Is the information from brainstorming included? Does at least one of the “knowns” listed cite what others already know about the topic?

The students were asked to use the iPads to find out what factors are required for growth and development of slime mold. They quickly determined that they thrive on oatmeal.



Another goal of Lab 2 was to move from a structured inquiry lab to a guided inquiry lab. The students investigated a teacher-presented question using student designed/selected procedures. The students wrote the steps of their procedure as they individually set up their investigation to answer the teacher-presented question: What factors are required for growth and development of slime mold? The students were again excited to have their own petri dish and set up their own investigation.

Lab 3: SCIENTIFIC METHOD- *Tetrahymena* (Appendix 6) began with Part 1: “Messing Around”; this was the students’ first experience with this level of inquiry (VAEI). The students were provided a copy of *Student Instructions* (Carolina) which included background information about *Tetrahymena*, and instructions for making a wet mount. The students used the *Student Instructions* background information to complete the knowledge probe. Each student made their own wet mount slide, and as a class “step-by-step” instructions for microscope use were demonstrated. The purpose of the “messing around” was to build knowledge about what *Tetrahymena* look like, and how they behaved; and to build skill and experience with microscopes and slide preparation. The students were given the entire class period to complete the exploration and data sections of Part 1, writing a conclusion was assigned for homework. Part 2: Brainstorming was completed in small groups the following day. Brainstorming produced many possible experimental questions including suggestions found in the *Student Instructions*, and the students were assigned to choose one question, write a hypothesis and investigative plan designed to be a fair test. Part 3: Further Investigation was completed three days later, allowing the instructor to check investigative plans and assemble supplies. Part 3

was an “open” inquiry (VAEI) which allowed the students to investigate a question that they formulated through student designed procedures.

Lab 4: SCIENTIFIC METHOD- Pill and Sow bugs (Appendix 7) required advanced planning in order to have organisms to study. The first day of the unit each student was given a plastic collection container and was assigned to bring at least ten pill bugs. The Lab similarly began with a “messaging around” and a knowledge probe, as in Lab 3. The students were provided the *Terrestrial Isopods Care Sheet* (Carolina) in the Drop box on the iPads in the classroom in order to complete the knowledge probe and find directions for handling the insects. Unlike the prior labs, class time was not given for group brainstorming; the students were introduced to a Google doc. The assignment was to list several “doable/testable” questions. The next day a brief class discussion determined the eight testing stations and students were randomly assigned a station. Students were allowed to swap stations. Part 2: Open Inquiry contained student formulated questions; however, the question studied possibly was not their original question. This lab was more chaos than control, which became a great “teachable” moment. There were many reasons for error: there were two different species, different size organisms, many of the bugs did not respond to any testing, and bugs were not separated after a test. Students found it very difficult to collect data, as well as hard to determine what data to collect. I heard many observations that were subjective, animal behavior types of responses. Examples included: “they don’t like salt”, “they like sugar”, “they are tired”, and “they are full”. I considered it a success because all students were engaged, discussing, and constantly revising their investigative plan.

Lab 5: SCIENTIFIC METHOD- Bacteria (Appendix 8) was completed using the living organism *Serratia marcescens*. Part 1: Building knowledge included first, a knowledge probe on-line to determine the conditions necessary for the best growth of the bacteria *Serratia marcescens* to grow; and second, a teacher discussion and demonstration of sterile technique to inoculate agar plates. Each student received one streaked mini petri dish with *Serratia marcescens* and was randomly assigned a temperature growth chamber to participate in Part 2: Controlled Experiment. This lab was a “structured” inquiry experience because students confirmed a principle through an investigation where the results were known from the knowledge probe completed in Part 1. Students were provided the claim that temperature has an effect on the growth rate and color of *Serratia marcescens*. Students wrote their questions based on the assigned growth chamber: room temperature, incubator at 37 degrees Celsius, or the refrigerator. Students also designed a data table to demonstrate their ability to organize data in a meaningful way (VAEI) by determining what data are significant, and the amount of data to collect (only their bacteria sample, all of their group samples, or the whole classes’ samples). Data were collected every day for the next three days, and then one-two times per week for the next three weeks, which extended into the next unit in Honors Biology. Next year I will begin bacteria earlier in the unit in order to incorporate a problem-based learning opportunity by challenging the students to grow a *Serratia marcescens* bacteria sample to match a picture example. The picture is a red bull’s eye center with circles of red and white surrounding it. This lab is best if two weeks are allowed for data collection, the results are much more interesting to analyze if students move their *Serratia marcescens* samples between the

different temperatures. This allowed students to have the opportunity to practice making predictions and hypothesizing.

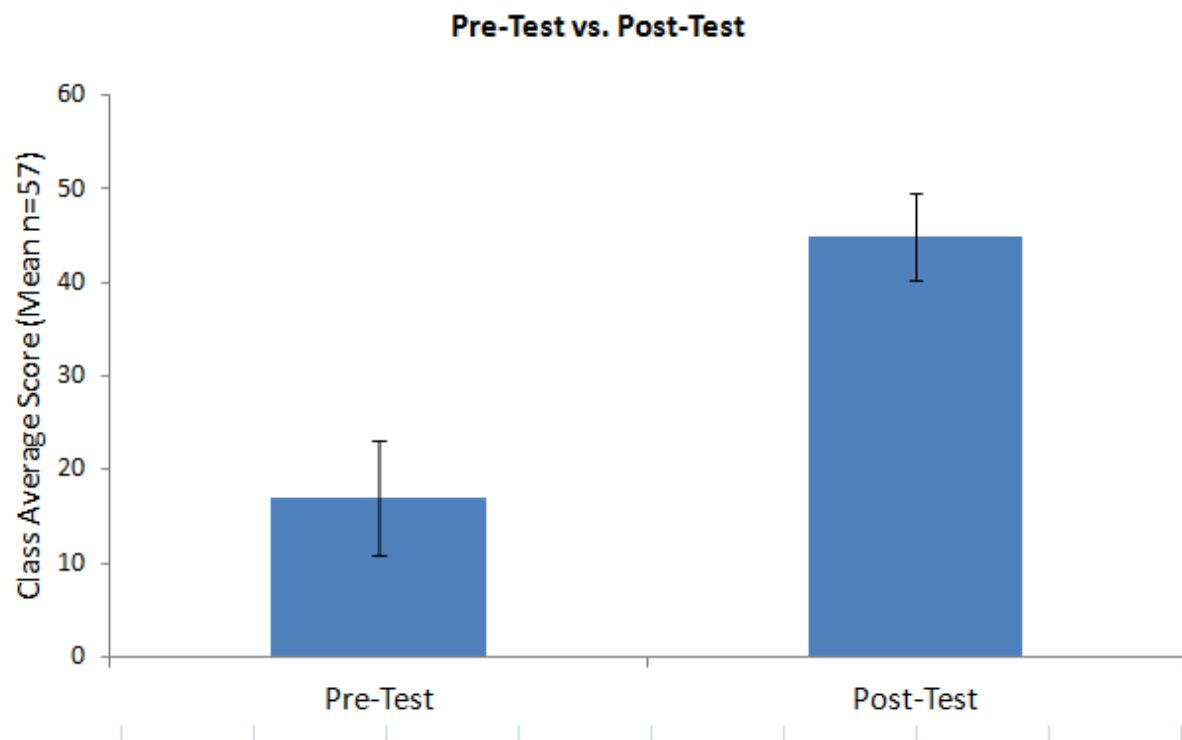
Lab 6: SCIENTIFIC METHOD- *Daphnia* was completed over a three day period and was a culmination of using living organisms for models to learn classification, and to practice inquiry-based science learning. Part 1 included “messing around” with the *Daphnia* to find its heart, learn techniques to count the heart rate, determine their average heart rate, and practice microscope use and preparing wet mount slides. Students also were taught how to control testing the organisms by separating *Daphnia* after testing by placing them in the “sick” tank. There was a class discussion about the problems and errors faced in the pill bug lab (Lab 4), and how some of those errors could be eliminated or decreased in our investigations with *Daphnia*.

The students were provided *Student Instructions* from *Effect of Drugs Kit* (Science Source Company) and assigned the knowledge probe as homework to find information and make predictions about one drug that was provided in the kit. The *Student Instructions* provided the procedure to follow, and students used a counter App on the iPads to count the heart beats of the *Daphnia*. Lab 6 was a very engaging “hands-on” lab that does not clearly fit VAEI *Levels of Inquiry Continuum*. It had elements of structured inquiry because the question and procedure were provided, and elements of open inquiry when they were able to generate their own question to test for a second test of Part 2: Effect of Drugs on *Daphnia*. Examples of student generated investigations included effects on *Daphnia* of sports drinks and artificial sweeteners. This lab provided practice in data collection, data analysis, and making graphs.

## RESULTS AND ANALYSIS

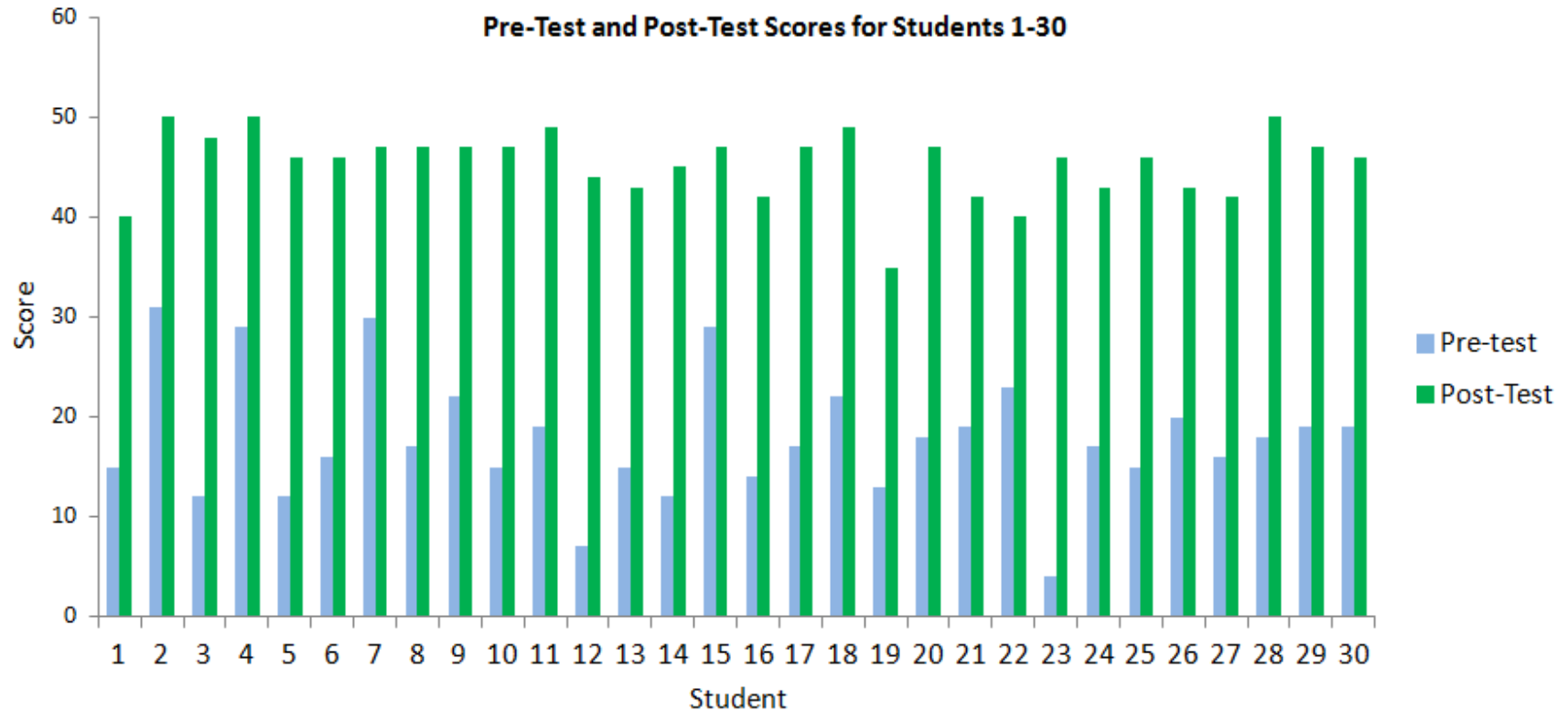
There were 57 students that completed the *Parental Consent and Student Assent Form* (Appendix 1), the unit pre-test, and the unit post-test (Appendix 2). The pre-test and post-test questions were identical. Their scores on each test were analyzed, and a t-test analysis ([http://www.physics.csbsju.edu/stats/Paired\\_t-test\\_NROW\\_form.html](http://www.physics.csbsju.edu/stats/Paired_t-test_NROW_form.html)) was done with  $p < 0.001$ . The test addressed the content the State of Michigan expects for students to learn in a high school biology class related to this unit, along with the Next Generation Science Practice of using models and planning and carrying out investigations.

The data for the pre-test and post-test t-test analysis were the result of using a rubric that scored each question separately. There were four (#8, #9, #10, #11) multiple choice questions, each worth one point and marked as either correct or incorrect. Questions #1-#7 vary in point value based on the completeness of responses required; on these questions, each student could receive partial credit. Figure 1 shows the class average score ( $n=57$ ) for the pre-test and post-test. All students improved from the pre-test to the post-test (Appendix 2). On average, students improved collectively by 60%, initially scoring an average 36% on the pre-test and achieving an average of 96% on the post-test. All students passed the post-test with the average score of 45 of 47 points, demonstrating mastery of the required benchmarks. Overall, comparison of the tests has a probability of less than 0.001 that the null hypothesis (that there is no difference between the two sets of data) is true. Results from all students indicate that the data were statistically significant, showing that there was a difference between the pre-test and the post-test data.

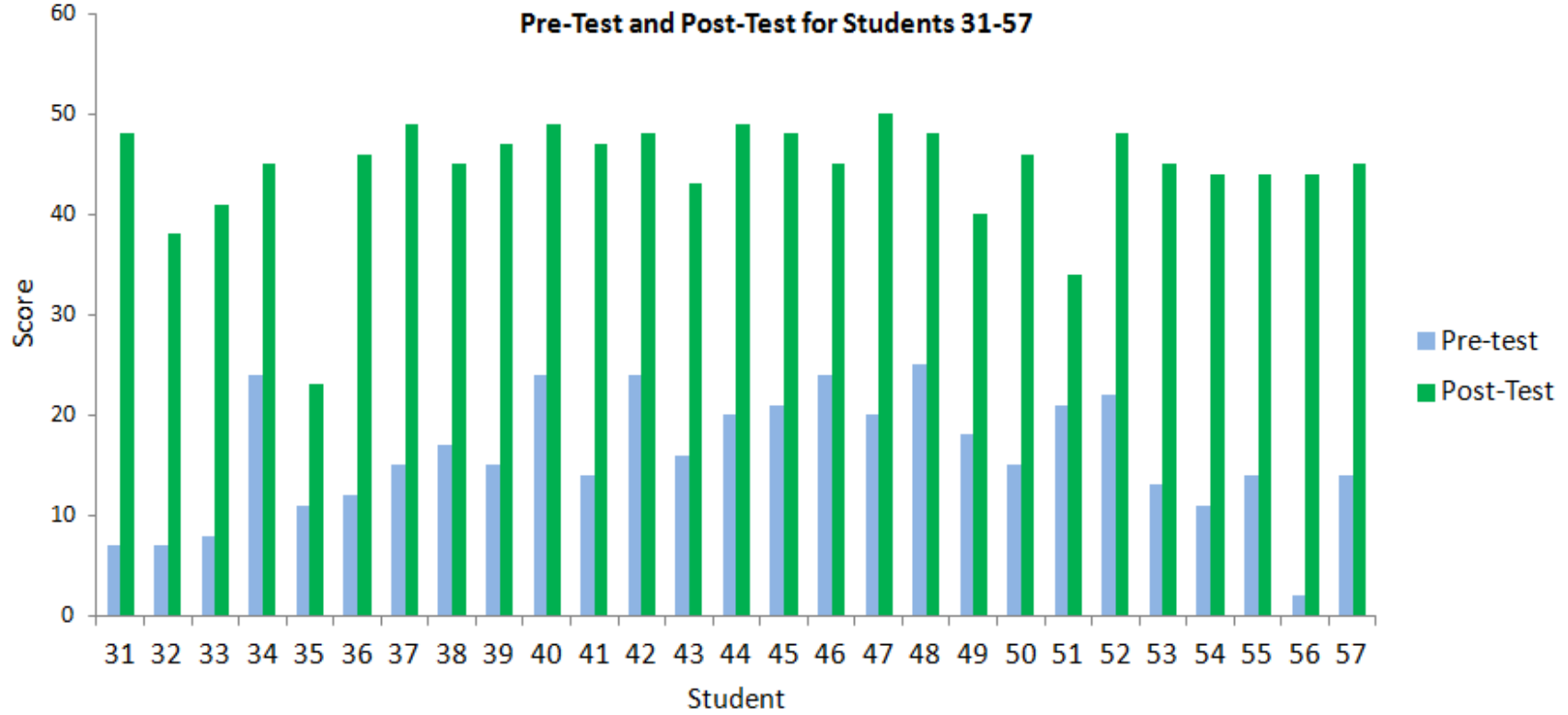


**Figure 1:** Average class score for Pre-Test and Post-Test

Figure 2 and Figure 3 show each individual student scores for the pre-test and post-test. Most students showed large margins of improvement by 60 to 80 percent. The lowest score was student 35; see Figure 5 for student 35 case study.

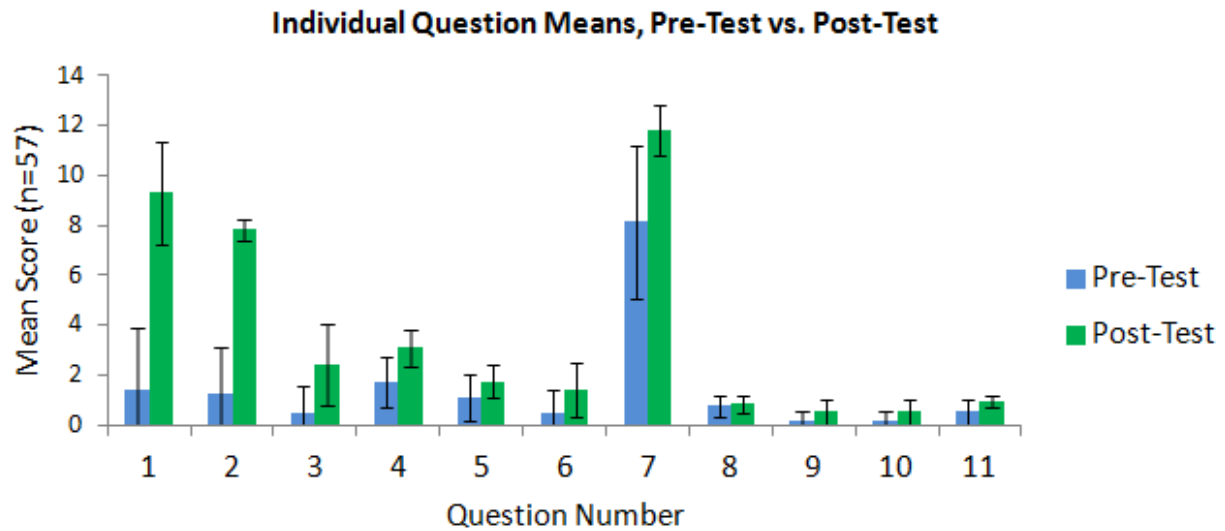


**Figure 2:** Individual student Pre-Test and Post-Test scores for students 1-30



**Figure 3:** Individual student Pre-Test and Post-Test scores for students 31-57

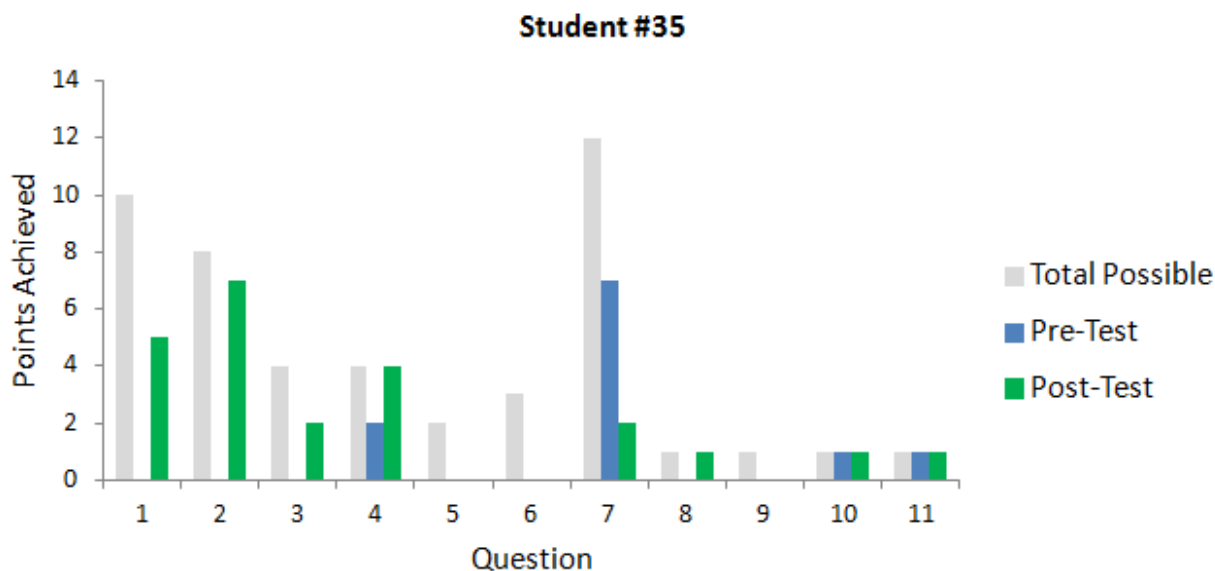




**Figure 4:** Pre-Test versus Post-Test results for each question

Figure 4 shows that all students improved on every question from the pre-test to the post-test, which total points for each question being 10, 8, 4, 4, 2, 3, 12, 1, 1, 1, 1 respectively. With the exception of Question #8 ( $p = 0.35$ ), all questions demonstrated a significant improvement in score for the class ( $p < 0.001$ ) as indicated by the paired student t-test. Error bars equal the standard deviation.

Figure 5 shows the pre-test and post-test scores on each question for the student that scored the lowest on the post-test score, student 35. Although this student passed the test by scoring an overall grade of 68%, and showed a 45% improvement from the pre-test score, the score was significantly lower than the rest of the class.



**Figure 5:** Pre-Test versus Post-Test results on each question for student 35

Student #35 was identified as an outlier within the class due to significantly lower performance on the post-test compared to the rest of the class. Figure 5 details the irregularity of the scores for each question. Most answers to questions demonstrated improvement from pre-test to post-test; however, question 7 shows a decrease. Overall, student #35 improved by 45% from pre-test to post-test and passed with a 68% on the post-test.

There was observed improvement in the students as a result of this unit in their *Formal Lab Reports* (Appendix 10). Students were permitted to redo a lab for full credit; and 92% of the students did not achieve an A on the first formal lab report. All students, except for two took advantage of the opportunity to redo the lab. The second formal lab report (Chlorella Lab in Ecology) only had five students desire to redo their lab in order to improve their score.

## DISCUSSION AND CONCLUSION

Using living organisms as models to anchor science instruction and discussion was an attempt to engage my students in content and processes. The instructional goal was to help them make personal sense about natural phenomena and to see inquiry-based classroom as the “coin of the realm” (Passmore et al. 2013). This means that students should be engaged in figuring out some aspect of a question, problem, investigation, model, or explanation with regard to some occurrence, observation or event they have experienced or explored. This point is essential if science instruction is to realize the potential of the *NGSS*’s interweaving of content and practice. I wanted students to carry the cognitive load in my class: to make observations, ask questions, and have the ability to test those questions. I expected them to know that it is important to construct models that explain phenomena, show how their models are consistent with their evidence, and explain the limitations of those models (MDE, 2011). I have found that teachers that tell students everything have students that will passively wait for that. It also is important to keep referring back to the framing questions as I developed and used both the living organism models and the inquiry-based science model. This keeps the focus on identifying the explanatory power of the model organism throughout the unit. For example, the slime mold was not able to make its own food, and has no mouth, a characteristic that can be explained to understand the classification and members of the Fungi Kingdom.

The QPOE<sub>2</sub> posters from VAEI were all around the classroom, and the QPOE<sub>2</sub> *Inquiry Framework App* (VAEI, 2013) is on the classroom set of iPads. I used QPOE<sub>2</sub> as a road map for inquiry science and to continuously identify not only where we are in the scientific method, but also to know where we are going. There was one flaw in the QPOE<sub>2</sub> *Inquiry Framework*. The

term *prediction* is used rather than *hypothesis* to describe the expected outcome of the investigation. The use of the term *hypothesis* is widespread throughout textbooks, literature, and research. The QPOE<sub>2</sub> *Inquiry Framework App* defines the following: some *predictions* are *hypotheses*; the *hypothesis* describes the relationship between the independent and the dependent variable. The *Formal Lab Report* (Appendix 10) identifies this step of the scientific method as *Hypothesis: Prediction*; the term *prediction* is defined as expected outcomes of the investigation and there can be several predictions.

This unit revealed that modeling could be a means to teach science in an authentic way. Rather than teaching the specific skills required at the start of the course as a separate entity, students were able to learn the scientific method, graphing, writing a formal lab report, using a microscope, using scientific equipment while learning about the classification of living organisms. The model organisms became the basis for all the subsequent units in Biology. Students did not struggle with the concepts and characteristics of bacteria throughout the year as they had in prior years. Bacteria are often not explained in detail in the students' Biology book (Glencoe, 2009). Rather, the text book identifies bacteria as an exception for characteristics of living organisms. An example from the Biology book is: "all living organisms are made of one or more cells" *except* bacteria do not have a cell with a nucleus and membrane-bound organelles as all other living organisms. Another example is: "DNA strands unwind as DNA is replicated" *except* bacteria do not long strands of DNA, bacteria have circular DNA. There is a common assessment given all Honors Biology and Biology students at the conclusion of the *Cellular Energy* unit. It contains a question that year after year was commonly answered incorrectly. The question asked about variables and controls for an

experiment utilizing bacteria growing in a petri dish, and students often answered with misconceptions and misunderstandings about bacteria growing in a petri dish. The students that participated in this study experienced bacterial growth of *Serratia marcescens*, and successfully answered the common assessment question. Their “hands-on” and “minds-on” experience with *Serratia marcescens* enabled the students to apply their knowledge successfully.

Using models can help students participate in *NGSS* principles such as communicating ideas, arguing based on evidence, and developing understanding of scientific and engineering practices and core ideas. Through the use of modeling to teach inquiry-based science, the students were able to practice developing, sharing, discussing, and modifying the scientific method to realize that it is not a static, linear process (Windschitl & Thompson, 2013). The “brainstorm” portions of the developed labs generated many potential questions to be studied; in addition, it provided the students opportunities to share, discuss and modify their ideas and prior knowledge. Lab 6: Scientific Method- *Daphnia* culminated with student presentations in which they presented their evidence and explained their conclusions. The students were very successful; all students scored 100% on Lab 6 and continued to use the communication, arguing, and developing scientific practice skills attained throughout the year of biology.

Overall, the data from the Pre-test and Post-test results (Figure 2, 3, 4) indicate that student comprehension was impacted by the hands-on, inquiry-based scientific method that comprised this unit. All of the lab activities were effective; the students were engaged, post-test scores showed improvement (Figures 2, 3, 4), and formal lab reports improved. Students were much more immersed when working with the living model organisms, either individually

or in groups, than when taking notes or having class discussions. I was very pleased with how eager they were to complete investigations, even to type the formal lab reports. Homework designed to complete a knowledge probe, or design the steps for the next investigation were always completed. I believe this eagerness was due to the fact that they could not design a procedure for their experiment without prior knowledge, nor begin their experiment without a procedure outlined. I also was very impressed with their ability to brainstorm many different variables and ask many potential open inquiry lab questions. I never heard a student say or complain that they didn't know what to do or couldn't think of anything to test.

The results indicate that teaching this unit met the intended goals. The immediate goals of the State of Michigan benchmarks on characteristics of life, the scientific method, and classification were clearly met by analysis of the post-test. The students all demonstrated successful growth and proficient learning in all the benchmarks as shown in Figure 2 and Figure 3. Figure 4 shows Pre-test and Post-test scores for each question. Questions 2, 6, and 8, were questions based on the characteristics of living organisms, question 1 was based on classification, and questions 3, 4, 5, 7, 9, 10, and 11 were based on the scientific method. The Next Generation Science Standards requiring developing and using models and planning and carrying out investigations as science and engineering practices were met as well. The use of LIVING model organisms and modeling inquiry-based science met the Next Generation Science Standards.

Besides the immediate goals for this unit, there were additional benefits throughout the rest of the Biology course. The students and I often would use the model organisms as examples in other units. Ecology was the next unit, and the students were considering the role

of all kingdoms in an ecosystem, not just plants and animals as in the past. I was grateful for their learning about bacteria at the beginning of the year because so often the text book will discuss a life process, and add the note “except for bacteria”. My students would pick up on that, and ask questions like: How do bacteria reproduce? Why don’t they have cells? How do they get energy? What do they eat? I was so pleased when the *Cellular Energy* on the common assessment was successfully completed with these students. The students also improved on another common assessment; the question asked about an experimental design that used petri dishes to grow yeast, and students had to identify the reason to put a lid on the petri dish. My students experienced the need to not contaminate the sample with their bacteria and slime mold experiments.

The students demonstrated significant improvement on their *Formal Lab Reports* throughout the Honors Biology class year. Students did not utilize the opportunity to revise/redo their *Formal Lab Reports*, because they were successful on their first submission. The rubric for *Formal Lab Reports* is based on the QPOE<sub>2</sub> *Inquiry Framework App* (VAEI) and students were successful on the following requirements:

Students were able to connect the hypothesis to the question and prior knowledge, and use the hypothesis to describe the relationship between the independent and dependent variables. Additionally,

- Students could design the investigation plan to be a fair test.
- Students were able to organize their data in a meaningful way and summarized, interpreted, and represented the data appropriately.

- The student's conclusions answered the investigative question and the evidence selected supported the claim.

Student #35 was identified as an outlier due to significantly poor performance on the post-test. While student #35 demonstrated significant improvements of 45% from pre-test to post-test, the irregularity of individual question scores combined with the overall low performance on the post-test indicate that the student may not be equipped for honors level curriculum. However, the significant improvement from pre-test to post-test scores may be attributed to the success of the inquiry based science strategy. Further studies would need to be performed in order to address this phenomenon: the identification of students developmentally ready and that have the work ethic to be placed in Honors Biology. In addition, a single outlier is consistent with previous experience in frequency of students that may not be appropriately placed in Honors Biology and may need to transfer into regular Biology.

I will begin Honors Biology with this unit in the future. Next year, I am considering adding more data collection to Lab 1, the germination of seeds activities. The students planted their seeds, and there were pea plants all over my room, which I used to discuss the life cycle of flowering plants during the Ecology unit. Test question #4 was a graph for interpretation showing the correlation of the mass of the plant to the number of days it had been growing. The students were asked to infer the height of a corn plant during the exponential period. The students' answers identified misconceptions and misunderstandings, however if the students experience taking the mass of their plant, and the water they add while graphing the information it may decrease their misconceptions and misunderstandings. This information will also be able to be re-visited during photosynthesis and cellular respiration.



Putting the observations together, I would conclude that using model organisms and modeling inquiry-based scientific practices are effective teaching strategies. The modeling practices and living organisms described in this thesis unit demonstrate science teaching as “effective method of inquiry into any subject matter” (NGSS, 2013). By focusing on big ideas blended with practices and crosscutting elements over time, students were able to do science by engaging in a scaffolding range of scientific practices, including creating and revising models that can explain phenomena and that change as more evidence is collected. I am excited to imagine the type of students whom emerge from Honors Biology after repeatedly experiencing instruction that supported them in constructing and revising models to explain phenomena! These students will be highly engaged in “open” inquiry and form a different breed of high school graduates who view science as an “effective method of inquiry” and who will serve as productive 21<sup>st</sup>-century citizens.

## APPENDICES

## APPENDIX 1

### PARENTAL CONSENT AND STUDENT ASSENT FORM

Dear Students and Parents/Guardians:

I would like to take this opportunity to welcome you back to school and invite you to participate in a research project, **Teaching Biology with Model Organisms**, which I will conduct as part of Honors Biology this semester. My name is Mrs. Dolores Keeley, I am your Honors Biology teacher this year and I am also a master's degree student at Michigan State University. Researchers are required to provide a consent form like this to inform you about the study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

**What is the purpose of this research?** I have been working on effective ways to teach the process of science using living organisms in Biology. I plan to study the results of this teaching approach on student comprehension and retention of the material. The results of this research will contribute to teachers' understandings about the best way to teach about science topics. Completion of this research project will also help me to earn my master's degree in Michigan State University College of Natural Science.

**What will students do?** You will participate in the instructional activities emphasizing the process of science using living organisms. You will complete the usual assignments, laboratory experiments and activities, class demonstrations, and pretest/posttests just as you do for any other unit of instruction. There are no unique research activities – participation in this study will not increase or decrease the amount of work that students do. I will simply make copies of students' work for my research purposes. I am asking for permission from both students and parents/guardian (one is sufficient) to use copies of student work for my research purposes. This project will continue from September through December 2013.

**What are the potential benefits?** My reason for doing this research is to learn more about improving the quality of science instruction. I won't know about the effectiveness of my teaching methods until I analyze my research results. If the results are positive, I can apply the same teaching methods to other science topics taught in this course, and you will benefit by better learning and remembering of course content. I will report the results in my master's thesis so that other teachers and their students can benefit from my research.

**What are the potential risks?** There are no foreseeable risks associated with completing course assignments, laboratory experiments and activities, class demonstrations, and pretests/posttests. In fact, completing course work should be very beneficial to students. The consent forms (where you say "yes" or "no") will be stored in a locked file cabinet and will not be opened until after I have assigned grades for this unit of

instruction. That way I will not know who agrees to participate in the research until after grades are issued. In the meantime, I will save all of your written work. Later I will analyze the written work only for students who have agreed to participate in the study and whose parent/guardian, have consented.

**How will privacy and confidentiality be protected?** Information about you will be protected to the maximum extent allowable by law. Student's names will not be reported in my master's thesis or in any other dissemination of the results of this research. Instead, the data will consist of class averages and samples of student work that will not include names. After I analyze the data to determine class averages and choose samples of student work for presentation in the thesis, I will destroy the copies of student's original assignments, tests, etc. The only people who will have access to the data are me, my thesis committee at MSU, and the Institutional Review Board at MSU. The data will be stored on password-protected computers (during the study) and in locked file cabinets in Dr. Heidemann's locked office at MSU (after the study) for at least three years after the study.

**What are your rights to participate, say no, or withdraw?** Participation in this research is completely voluntary. You have the right to say "no". You may change your mind at any time and withdraw. If either the student or parent/guardian requests to withdraw, the student's information will not be used in this study. There are no penalties for saying "no" or choosing to withdraw.

**Who can you contact with questions and concerns?** If you have concerns or questions about this study, please don't hesitate to contact the researcher Mrs. Dolores Keeley: 2200 Pettis Ave, Ada, MI 49301; [dkeeley@fhps.net](mailto:dkeeley@fhps.net); 616-493-8830; and/or Dr. Merle Heidemann: 118 North Kedzie Lab, East Lansing, MI 48824; [heidma2@msu.edu](mailto:heidma2@msu.edu); 517-432-2152 x107.

If you have questions or concerns regarding your role as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if desired, MSU Human Research Protection Program at: [irb@msu.edu](mailto:irb@msu.edu)

**How should I submit this consent form?** Please complete the attached form. Both the student and parent/guardian must sign the form. Please return with your student a form indicating interest either way. Return the form in the sealed envelope to Mr. Steve Harvey, Principal

Name of science course: Honors Biology

Teacher: Mrs. Dolores Keeley

School: Forest Hills Eastern High School

**Parents/guardians should complete this following consent information:**

I voluntarily agree to have \_\_\_\_\_ participate in this study.  
(Student Name)

**Please check all that apply:**

**Data:**

\_\_\_\_\_ I give Dolores Keeley permission to use data generated from my child's work in class for her thesis project. All data shall remain confidential.

\_\_\_\_\_ I do not wish to have my child's work in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of their participation in this research.

**Photography, audio taping, or videotaping:**

\_\_\_\_\_ I give Dolores Keeley permission to use photos, or videotapes of my child in the class room doing work related to this thesis project. I understand that my child will not be identified.

\_\_\_\_\_ I do not wish to have my child's images used at any time during this thesis project.

**Signatures:** \_\_\_\_\_  
(Parent Signature) (Date)  
\_\_\_\_\_  
(Student Signature) (Date)

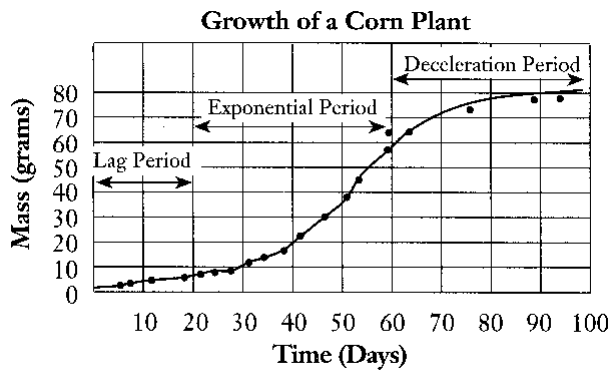
**\*\*\*Important\*\*\***

**Please return this form in the sealed envelope to Mr. Steve Harvey, Principal.  
(Front Office)**

## **APPENDIX 2**

### **Honors Biology Pretest / Posttest! Show what you know!!!!**

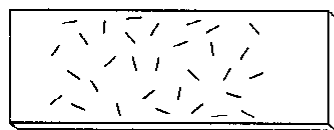
1. Biology is the study of living organisms. Biologists are the scientists that study and organize all living organisms. How are living organisms classified? List the main divisions/groups that biologists use and give an example of a living organism in that division.
2. Biologists determine that something is living based on what characteristics?
3. Discuss how a biologist might carry out quantitative and descriptive research on a species of monkeys.



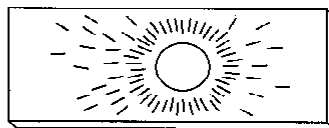
**Figure A2-1:** Growth of a corn plant in grams over time in days

4. The graph in Figure A2-1 shows the three stages in the growth of a corn plant from a seed to a mature plant. Study the graph and then answer the questions.
  - a. From Figure A2-1, predict the mass of the plant at day 110.  
\_\_\_\_\_
  - b. Using Figure A2-1, what might you infer about the height of the plant during the exponential period?
  - c. What do you think is happening during the lag period in Figure A2-1?
  
5. Sugar dissolves in, or mixes completely with, water. The solubility of a substance in water is determined by measuring the maximum amount of the substance that dissolves in a given amount of water at a given temperature. HYPOTHESIS: The solubility of sugar in water increases as the temperature of the water decreases. Identify the independent and dependent variables.

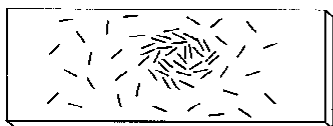
Paramecia are single-celled, microscopic organisms that live in freshwater environments. A student prepared several covered slides of paramecia in freshwater. The student added different stimuli and observed the behavior of the organisms under the microscope. The diagrams in Figure A2-2 show what the student viewed.



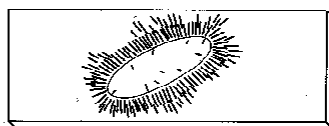
**In freshwater**



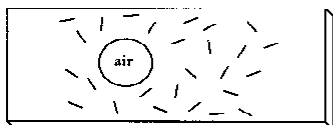
**Reaction to drop of  
dilute saltwater solution (0.5%)**



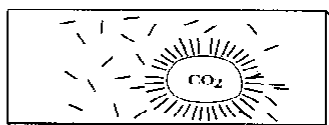
**Reaction to drop of vinegar**



**Reaction to piece of food**



**Reaction to air bubble**



**Reaction to carbon dioxide bubble**

**Figure A2-2:** Paramecia response to stimuli

6. Predict how a population of paramecia would respond to the addition of a drop of 10% salt solution. Give reasons for your prediction. Use Figure A2-2.

What purpose (for the observer) does observing the response to a piece of food serve? Use Figure A2-2.

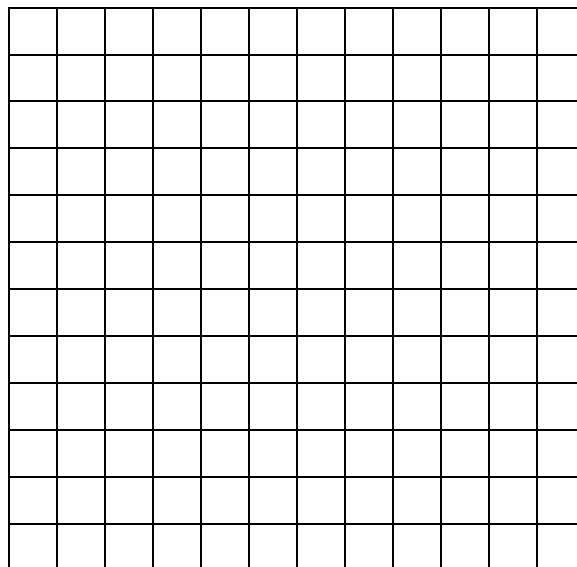


Day	Height of Plant A in cm (no fertilizer)	Height of Plant B in cm (1g fertilizer)
1	2.0	2.0
3	2.2	2.2
5	2.3	2.4
7	2.4	2.6
9	2.5	2.8
11	2.6	3.0

**Table A2-1:** Height of plants A and B over time in days

7. What inference can be made from the results in Table A2-1?

Make a graph that compares the growth of the plants as shown in Table A2-1.



### Multiple Choice

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

\_\_\_\_ 8. Students in a biology class ran an experiment on a type of flowering plant. Their goal was to find the optimal time in the plant's life for flowering. What time period will provide the most flowering plants? Use Table A2-2 to determine your answer.

Table A2-2	
Day	Number of Plants Flowering
2	6
4	12
6	18
8	22
10	8

**Table A2-2:** Time table in days for number of flowering plants

- a. 5–6 days
- b. 6–7 days
- c. 7–8 days
- d. 8–9 days

\_\_\_\_ 9. Which best describes the difference between an observation and an inference?

- a. You can record an observation; an inference is an idea.
- b. You make an inference before you make observations.
- c. An observation is a conclusion; an inference is a hypothesis.
- d. An observation is based on evidence, an inference is not.

\_\_\_\_ 10. Tasha is testing the effect of blue-colored light on the growth of tomato plants. Which is the independent variable in this experiment?

- a. light color
- b. light intensity
- c. amount of light
- d. temperature of light

\_\_\_\_\_ 11. A researcher is interested in the effects of nitrate and phosphate on plant growth and sets up an experiment in which groups of five plants are given 1, 2, and 3 grams of nitrate and 1, 2, and 3 grams of phosphate in all combinations over a period of one month. The researcher measures plant height and weight at the end of the experiment.

What is missing in this experimental design?

- a. a control
- b. an independent variable
- c. a dependent variable
- d. a constant

## APPENDIX 3

### Classroom Inquiry and Its Variations

	Messing About is used in conjunction with other levels of inquiry along the inquiry continuum.	Less ← Amount of Student Self-Direction → More More ← Amount of Direction from Teacher or Materials → Less			
Levels	Messing About	More structured inquiry (Levels 1 and 2) is used to gradually develop students' abilities to conduct more open inquiry (Levels 3 and 4). Students will often experience all levels of inquiry during a single unit with related scientific concepts.			
		1 – Confirmation	2 – Structured	3 – Guided	4 – Open
Overview	Students build needed prior knowledge, skills, and experience through direct exploration	Students investigate a teacher-presented <b>Question</b> or problem to confirm a principle where the results are known in advance	Students investigate a teacher-presented <b>Question</b> or problem through a prescribed <b>Investigation Plan</b>	Students investigate a teacher-presented <b>Question</b> or problem using student-designed or selected <b>Investigation Plans</b>	Students investigate topic-related <b>Questions</b> or problems that are student-formulated through student-designed or selected <b>Investigation Plans</b>
Students are provided with	<ul style="list-style-type: none"> <li>Crosscutting Concept/ Core Idea/Context</li> <li>Materials</li> </ul>	<ul style="list-style-type: none"> <li>Crosscutting Concept/ Core Idea/Context</li> <li>Materials</li> <li><b>Question/Problem</b></li> <li><b>Investigation Plan</b></li> <li>Expected results/Solution</li> </ul>	<ul style="list-style-type: none"> <li>Crosscutting Concept/ Core Idea/Context</li> <li>Materials</li> <li><b>Question/Problem</b></li> <li><b>Investigation Plan</b></li> </ul>	<ul style="list-style-type: none"> <li>Crosscutting Concept/ Core Idea/Context</li> <li>Materials</li> <li><b>Question/Problem</b></li> </ul>	<ul style="list-style-type: none"> <li>Crosscutting Concept/ Core Idea/Context</li> <li>Materials</li> </ul>
What students do	<ul style="list-style-type: none"> <li>Explore</li> <li>Record <b>Observations</b></li> <li>Conduct <b>Data Analysis</b></li> <li>Generate <b>Questions</b></li> </ul>	<ul style="list-style-type: none"> <li>Carry out a teacher-designed activity</li> <li>Record <b>Observations</b></li> <li>Conduct <b>Data Analysis</b></li> <li>Verify results with text/manual</li> <li>Complete an <b>Evaluation</b> at the end of the activity</li> <li>Communicate results</li> </ul>	<ul style="list-style-type: none"> <li>Make <b>Predictions</b></li> <li>Carry out a prescribed <b>Investigation Plan</b></li> <li>Record <b>Observations</b></li> <li>Conduct <b>Data Analysis</b></li> <li>Construct <b>Explanations</b> or design solutions that are supported with evidence and reasoning</li> <li>Complete an <b>Evaluation</b> at the end of the investigation.</li> <li>Communicate results</li> </ul>	<ul style="list-style-type: none"> <li>Complete a <b>Knowledge Probe</b></li> <li>Make <b>Predictions</b></li> <li>Design and carry out an <b>Investigation Plan</b> to test the teacher-provided <b>Question</b> or problem</li> <li>Record <b>Observations</b></li> <li>Conduct <b>Data Analysis</b> or design solutions that are supported with evidence and reasoning</li> <li>Complete <b>Evaluations</b> throughout their investigations</li> <li>Communicate results</li> </ul>	<ul style="list-style-type: none"> <li>Generate <b>Questions</b> or define problems</li> <li>Complete a <b>Knowledge Probe</b></li> <li>Make <b>Predictions</b></li> <li>Design and carry out an <b>Investigation Plan</b> to test their <b>Questions</b> or problems</li> <li>Record <b>Observations</b></li> <li>Conduct <b>Data Analysis</b></li> <li>Construct <b>Explanations</b> or design solutions that are supported with evidence and reasoning</li> <li>Complete <b>Evaluations</b> throughout their investigations</li> <li>Communicate results</li> </ul>
What teachers do	<ul style="list-style-type: none"> <li>Establish a socially and language rich learning environment</li> <li>Nurture habits of minds</li> </ul>	<ul style="list-style-type: none"> <li>Establish a socially and language rich learning environment</li> <li>Nurture habits of mind</li> <li>Provide the <b>Question</b></li> <li>Conduct a <b>Knowledge Probe</b> to elicit students' prior knowledge</li> <li>Provide the <b>Investigation Plan</b></li> <li>Tell students how to conduct <b>Data Analysis</b></li> <li>Tell how to use evidence to construct <b>Explanations</b> or design solutions</li> <li>Give steps and procedures for <b>Evaluation</b></li> <li>Give steps and procedures for communication</li> </ul>	<ul style="list-style-type: none"> <li>Establish a socially and language rich learning environment</li> <li>Nurture habits of mind</li> <li>Provide the <b>Question</b></li> <li>Conduct a <b>Knowledge Probe</b> to elicit students' prior knowledge</li> <li>Provide the <b>Investigation Plan</b></li> <li>Suggest <b>Data Analysis</b> strategies</li> <li>Give possible ways to use evidence to construct <b>Explanations</b> or design solutions</li> <li>Give possible connections to scientific knowledge</li> <li>Guide the completion of the <b>Evaluation</b></li> <li>Provide broad guidelines to sharpen communication</li> </ul>	<ul style="list-style-type: none"> <li>Establish a socially and language rich learning environment</li> <li>Nurture habits of mind</li> <li>Help learners determine if their <b>Investigation Plans</b> make sense</li> <li>Guide the construction of <b>Explanations</b> or design of solutions from evidence</li> <li>Encourage <b>Evaluation</b> throughout the investigation</li> <li>Direct learners toward areas and sources of scientific knowledge</li> <li>Coach the development of communication</li> </ul>	<ul style="list-style-type: none"> <li>Establish a socially and language rich learning environment</li> <li>Nurture habits of mind</li> </ul>

Adapted from NRC 2000, 2012; Bell, Smetana, & Binns, 2005; Banchi and Bell, 2008

Figure A3-1: Classroom Inquiry and its Variations

## APPENDIX 4

### LAB 1: SCIENTIFIC METHOD – SEED GERMINATION

#### Part 1: Structured Inquiry

**Question:** What factors are required for seed germination?

**Materials:** seeds, baggies, paper towel, water, and other necessary factors

**Hypothesis:** A seed requires the following in order to germinate:

**Procedure:**

1. Each person has 4 seeds, your goal is to have the seeds germinate (sprout) with the minimum number of required factors.
2. Draw a picture and describe your experimental design.
3. Place your seeds in the appropriate location.

**Data:**

Time	Seed 1	Seed 2	Seed 3	Seed 4
24 hours				
48 hours				
72 hours				

**Class Results:**

**Conclusion:** The factors required for a seed to germinate are \_\_\_\_\_.

#### Part 2: Brainstorming

**Question:** What factors influence seed germination?

**Materials:** markers and large newsprint paper

**Procedure:**

1. Each lab group takes a sheet of paper and set of markers.
2. Brainstorm a list of 10-20 variables that might influence seed germination (sprouting).
3. All members of the group participate by taking turns recording ideas on the paper.
4. Place headings on the chart that include:
  - a. Factor (variable)
  - b. Predicted effect
  - c. Explanation for prediction
5. Post the completed charts on the walls of the room. These are sources of controlled variables.

### Part 3: Designing a Controlled Experiment

Your group has been asked to investigate a claim that “Miracle Gro” speeds up seed germination. We will use seeds and germination bags for the experiment. Your group will vary the concentration of “Miracle Gro” as the independent variable, and test its effects on seed germination.

#### Materials:

- ☐ seeds
- ☐ 50mL 5% “Miracle Gro”
- ☐ 5 plastic bags
- ☐ 5 paper towels
- ☐ graduated cylinders

#### Procedure:

1. Obtain a copy of the Experimental Design Guide.
2. Complete the Experimental Design Guide for an experiment to test whether or not Miracle Gro speeds up seed germination.
3. Follow your teacher’s instructions to make a dilution of Miracle Gro.
4. Instead of planting your seeds in soil, you will plant them in a germination bag. You make a germination bag by placing 1 folded piece of paper towel in the plastic bag.
5. Add 10mL of solution to the bag.
6. Label each bag with your name, hour, date, and the concentration used.
7. Plant approximately 5 seeds in a horizontal line approximately in the middle of the paper towel.
8. Using masking tape, hang your germination bags on a cabinet door in the room
9. Construct a data table with a title. Your title must include the variables and the organism studied. Put the independent variable in the left-hand column.
10. Collect data over several days.
11. Summarize the data in graph form and write a conclusion on the experiment.

### Part 4. Designing an Open Inquiry Experiment

Choose one factor from the Part 2 brainstorming session, or another factor that you would like to investigate. Design and carry out an experiment to determine the effect of the factor on seed germination.

This will be your first formal lab write-up. You will have 2 weeks to conduct your experiment.

**Honors Biology**  
**EXPERIMENTAL DESIGN GUIDE**

**TITLE** \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**HYPOTHESIS**  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**INDEPENDENT VARIABLE**  
\_\_\_\_\_

**MEASUREMENT OF INDEPENDENT VARIABLE**  
\_\_\_\_\_

**NUMBER OF TRIALS** \_\_\_\_\_

**DEPENDENT VARIABLE**  
\_\_\_\_\_

**MEASUREMENT OF DEPENDENT VARIABLE**  
\_\_\_\_\_

**CONTROL** \_\_\_\_\_

**OTHER CONTROLLED FACTORS (AT LEAST 5)**  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**PROCEDURE / MATERIALS / DATA**  
**(USE BACK SIDE OF PAPER)**

**CONCLUSION (ANSWER QUESTION)**  
\_\_\_\_\_  
\_\_\_\_\_

**REASONS FOR ERROR**  
\_\_\_\_\_

## APPENDIX 5

### LAB 2: SCIENTIFIC METHOD – SLIME MOLD (*Physarum polycephalum*)

#### Part 1: Structured Inquiry

**Question:** What factors are required for growth and development of slime mold?

**Hypothesis:** Slime mold is a living organism that requires:

**Knowledge Probe:**

**Materials Required:**

**Procedure:**

1.

2.

**Data (Individual & Class)**

**Conclusion:** The factors required to grow slime mold are:



## APPENDIX 6

### LAB 3: SCIENTIFIC METHOD – *Tetrahymena*

#### Part 1: Structured Inquiry/"Messing Around"

**Question:** How do *Tetrahymena* behave, and what do they look like?

**Knowledge Probe:**

**Hypothesis:**

**Materials Required:** Slide, cover slip, microscope

**Procedure:**

1. Make a wet mount slide with *Tetrahymena* and observe their structure and behavior.
2. Draw a picture, and write descriptions of your observed behavior.

**Data:**

**Conclusion:**

## **Part 2: Brainstorming**

Pose several questions you would like to investigate using *Tetrahymena*. You may use ideas from *Student instructions; Additional Suggestions*. You may also search the internet for ideas!

## **Part 3: Further Investigation**

Choose 1 question from ***Brainstorming*** to investigate and complete the following:

**Question:**

**Hypothesis:**

**Materials Required:**

**Procedure:**

## **APPENDIX 7**

### **LAB 4: SCIENTIFIC METHOD – Pill bugs/ Sow bugs (*Porcellio/Armadillidium*)**

#### **Part 1: Structured Inquiry/"Messing Around"**

**Question:** How do **Pill bugs/ Sow bugs** behave, and what do they look like?

**Messing Around Observations:**

**Knowledge Probe:** (See *Terrestrial Isopods Care Sheet* in Dropbox on the iPads)

**Question to be studied:**

**Hypothesis:**

#### **Part 3: Designing a Controlled Experiment**

Design a procedure to test the question you asked.

## APPENDIX 8

### LAB 5: SCIENTIFIC METHOD – BACTERIA

#### Part 1: Building Knowledge

**Question:** What factors are required for *Serratia marcescens*?

**Hypothesis:** *Serratia marcescens* is a bacteria that grows best

**Knowledge Probe:**

#### Part 2: Designing a Controlled Experiment

Your group has been asked to investigate a claim that temperature has an effect on the growth and color of *Serratia marcescens*.

**Question:**

**Hypothesis:**

**Materials:**

Samples of *Serratia marcescens* in nutrient agar

Dark growth areas at room temperature, warm incubator, and cold refrigerator

**Procedure:**

1. Label your *Serratia marcescens* sample and place in the assigned temperature growth chamber.
2. Make a data table to record class results.

#### Part 3. Designing an Open Inquiry Experiment to solve a problem

## APPENDIX 9

### The Characteristics of Life

LIVING "ORGANISMS"	NONLIVING "THINGS"
1.	1.
2.	2.
3.	3.
4.	4.
5.	5.
6.	6.
7.	7.
8.	8.
CHARACTERISTICS OF LIVING ORGANISMS	HOG RACES
1.	1.
2.	2.
3.	3.
4.	4.
5.	5.
6.	6.
7.	7.
8.	8.

## **APPENDIX 10**

### **HONORS BIOLOGY: WRITING FORMAL LAB REPORTS**

#### **FORMATTING**

- 12 pt New Times Roman/Arial font; 1" margins; double space text (not titles/headings)
- Third person only (no personal pronouns)
- Name, date, and hour in upper **LEFT** corner.

#### **Title** (centered on page)

- Indicate clearly & concisely the subject and scope of the report.

#### **Introduction: Knowledge Probe**

- This is a paragraph giving the reader the background and prior knowledge needed to understand where the question developed. This will introduce the topic and have it flow into the question much like an introduction in an English paper.

#### **Question**

- What question will be answered by the collected data? What is the purpose of the investigation?

#### **Hypothesis: Predictions**

- Hypothesis is a single statement telling the expected answer to your question.
- Predictions are expected outcomes of your investigation. There can be one or several predictions. They can be written as "If...then..." statements.

#### **Investigative Plan**

- Step-by-step directions of the method and materials used. Management of the controls and manipulation of the variables included.
- Procedures are numbered; drawings and diagrams may be included.

#### **Data: Observations**

- Tables, and/or graphs of all quantitative and qualitative observations.
- Data summarized in a narrative form.

#### **Conclusion: Explanation and Interpretation**

- Interpret the collected data and use it to support or falsify the restated hypothesis.
- Explain the significance of the results and relate it to any background information
- Include some possible questions for further study generated by the results of this experiment.

#### **Evaluation**

- Explain any sources of error and how they may have affected your results.
- Consider and explain possible improvements for the experiment if it were to be repeated.

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