Engaging Learners Through Inquiry-Based Instruction to Promote Evidence-Based Writing in Advanced Placement Biology

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Engaging Learners Through Inquiry-Based Instruction to Promote Evidence-Based Writing in Advanced Placement Biology

by

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Chapter One: Introduction

In 1957 the Soviet Union launched the first-ever satellite, Sputnik. The United States was shocked. It suddenly became evident that the United States was no longer the most superior country in math and science. Hence, the boom of the “space race”, and along with it, the “National Defense Education Act” signed into law September 2nd 1958. Suddenly science education was among the nation’s top priorities, and science teachers all over the country were trying to engage and educate young “would-be” scientists for the future. Science teachers were motivated, students were enlightened. But has that passion for science education worn off over the years? Today the number of students who want to pursue careers in math, science or engineering is diminishing fast (Dean, 2007). It seems as though our educational investment in the space race has finally worn off. According to an article in the popular press, a survey conducted by Harris Interactive in late 2007 polled over 1,300 Americans aged 18 and older and found that U.S. adults are not well educated in science. Furthermore, 44 percent of U.S. adults grade the quality of science education in this country at a “C” or worse, further stating that the current level of science education in this country is not adequate (Nagel, 2008).

Why this inadequacy? Is it the lack of quality instruction by science teachers around the country? Are teachers not effectively engaging their students in meaningful learning? These questions and more have sparked a pedagogical shift in science education that suggests science should be taught more through a student inquiry-based approach as opposed to the traditional didactic instructional method.

Researchers describe inquiry as an instructional method where students need to discover science through engaging experimentation rather than be spoon-fed pre-discovered scientific facts (Dean, 2007). This active discovery, researchers claim, is what enhances concept knowledge, comprehension and interest in science. This is the main focus of this literature review; the value of engaging students through inquiry-based instruction that promotes evidence-based writing.
First this project will take a brief look at the history of national standards and student engagement levels in public education. Next we will evaluate the current state of student literacy skills in the United States. And lastly, this project will analyze strategies for improving science instruction such as inquiry learning and evidence-based writing.
Chapter Two: Review of the Literature

A Brief History of National Standards and Curriculum

Advanced Placement

The College Board, a non-profit organization based in New York City, has run the Advanced Placement (AP) program since 1955. The AP program is designed to give high school upper classmen an opportunity to enroll in challenging college-level courses at a reduced cost (The College Board, 2011; Nagrath, 2011). Students who perform well on the AP exams can receive college credit, and sometimes even replace freshman level courses they would have to take in college. In 2006, one million students from around the country took over two million AP exams. In addition to maintaining guidelines for higher-level courses in various subject areas, the College Board has also developed programs that support teachers and universities. These programs and activities are funded by the fees students pay for AP exams which in 2011, was $87 (The College Board, 2011).

Undoubtedly, the AP program has had a long-standing reputation for setting high standards and expectations. Some scholars, however, argue that the standards are a little too high. Nagrath (2011) explains “It is not that the AP courses are not challenging; the problem is that they are a little too challenging” (p. 7). She further states “For years, critics of the program have complained that the courses are too ambitious, covering an almost encyclopedic scope of material” (p. 7). This, as Nagrath explains, forces teachers around the country to literally “teach to the test”, allowing very little opportunity for teachers to dive deeper into a particular area in the curriculum. Much of the AP curriculum encourages rote memorization and recalling of facts, as opposed to critical thinking and problem solving skills which are necessary to be successful in higher education and the work force. This has lead to AP students becoming jacks of all trades, and consequently, masters of none.

After several years of criticism, the College Board has decided to make a change. The College Board has already made changes to the French and German language courses, as well as AP World history. Slated for 2012-13 is
a full-scale revamping of the AP Biology, Latin and Spanish Courses. In 2013-14 school year, the College Board plans on revising the AP U.S. History course as well (Nagrath, 2011).

The new direction the College Board is taking with the AP curriculum seems to be focused more on depth, and less on scope. According to Musante (2011) the new AP Biology curriculum emphasizes critical thinking, application of biological concepts, as well a quantitative reasoning and the development of scientific skills. Musante argues that the changes are going to be so substantial that it will even influence traditional undergraduate biology courses taught at colleges and universities all over the country.

According to Nagrath (2011), the College Board is doing away with the canned labs that are often considered as verification-based, time-consuming and boring. The new lab activities are supposed to stress creative hands-on investigations, which the College Board hopes, will encourage a deeper understanding and foster a true love of learning.

**Reasons for Change**

**Student interest in science.**

Much research has been focused on students’ perceptions towards science and the differences in perceptions between boy and girls. Research by Quinn and Lyons (2011) explains “if students enjoy school science, remain engaged in it and develop competence, their developing identities are more likely to become consonant with science-related behaviours and choices” (p228). They claim that students’ self-efficacy and self-concept are strongly correlated to student’s attitudes towards science. Furthermore, students with high self-efficacy typically have higher aspirations and motivation to make secondary, post-secondary and career choices in science (Quinn and Lyons, 2011). So how do students today view school science?

Studies reviewed by Osborne (2008) suggest that at age 10 several students, both males and females, are generally interested in science; that interest, however, subsequently declines over time. By the time these students reach secondary school, students are much less interested in science. Dillon (2009) agrees by stating “In recent years,
many studies have highlighted an alarming decline in young people’s interest for key science studies and mathematics” (p. 204). This is alarming considering those students’ intentions regarding potential careers are often formed in early high school (Quinn and Lyons, 2011). Even more alarming is the comparison of boys and girls perceptions towards science. Several researchers have found that girls are much less interested and less likely to pursue careers in science when compared to boys (Osborne, 2008; Quinn and Lyons, 2011; Yeung et al., 2010).

The lack of student interest in science is a major concern for not only teachers, but society as well. The number of students enrolling in science-based post-secondary education and career paths is decreasing over time (Osborne, Simon and Collins, 2003). Osborne, Simon and Collins, argue that this is particularly troubling considering that science and the proportionate number of engineers and scientists are correlated to economic performance of a society. Osborne explains that the number of engineers and scientists in an economically successful country like Japan has roughly 67 times more engineers and scientists per million of population than economically challenged countries in Africa.

Student science literacy skills.

The famous Brazilian educator and major influential theorist of critical pedagogy, Paulo Freire, was once quoted “Literacy is an active phenomenon. Its power lies not in a received ability to read and write, but rather in an individual’s capacity to put those skills to work in shaping the course of his or her own life.” This quote reminds us how important language and science literacy can be in the high school classroom. Students will ultimately have to make decisions on best ways to conserve and utilize alternative energy, resolve global environmental issues such as climate change, or whether or not they undergo genetic screening for debilitating genetic disorders in their future offspring. Students have no other place to learn about these important socioscientific issues but in the classroom. Thier (2010) agrees that one of the main priorities for science teachers is to “help students improve their language skills within the context of science, because all teachers need to support literacy within the context of their discipline” (p.33). Teachers of all subject areas are inevitably endowed with an undeniable responsibility to promote literacy and language skills in the classroom.
Research by Dillon (2009) defines science literacy as “an evolving combination of the science-related attitudes, skills, and knowledge students need to develop inquiry, problem-solving, and decision-making abilities, to become lifelong learners, and to maintain a sense of wonder about the world around them” (p. 209). This all-encompassing definition alludes to the overall importance of developing and maintaining a society that is science literate. Dillon explains that national wealth depends heavily on competing in international markets. In order to compete successfully a nation must have a strong research and development base. Investing in a steady stream of scientifically literate people is crucial to man the demand for future researchers and developers, and remain competitive in today’s global market.

Unfortunately, however, the number of students that want to enter careers in math and science is diminishing fast (Dean, 2007; Dillon, 2009). This has not gone unnoticed as several states have begun revamping their educational standards and curriculum. The Common Core State Standards (CCSS) is a new educational initiative set forth by numerous states around the United States to better prepare students for college and the workforce (Common Core State Standards Initiative, 2011). According to the CCSS, too many students are graduating high school only to drop out and be unsuccessful in college and/or the workforce. The CCSS argues that the reason for this is because too many students graduate high school unable to read and write effectively. The CCSS calls for a revamping of curriculum that emphasizes the literacy skills necessary to be successful at post-secondary levels. One of the major “shifts” in the CCSS initiative is to encourage students in science class to make connections between text and their own experimental evidence. Students should be able to analyze their evidence to make evidence-based claims and arguments that either support or refute arguments made in text. This, as CCSS argues, is an important step for students to become successful consumers of science (Common Core State Standards Initiative, 2011).

**Strategies for Improving Science Instruction**

**Engaging the learner.**

In the field of education, arguably nothing is more critical to academic success than student engagement. Researchers Appleton and Lawrenz (2011) describe student engagement as “a commitment to, valuing of, and
connection with the people, educational goals, and outcomes promoted by a school” (p. 144). They further explain that engagement is “the student’s psychological investment in and effort directed toward learning, understanding, or mastering the knowledge, skills, or crafts that academic work is intended to promote” (p. 143-144). To adequately examine this educational requisite this literature review will first outline the importance of student engagement in today’s classroom. Next we will explain how student engagement levels are affected by teachers and the community. And lastly we will focus on how levels of student engagement in science can differ between adolescent boys and girls.

Amid higher expectations and concerns over international achievement gaps, educators and researchers have searched for methods to improve student performance. Researchers Appleton and Lawrenz (2011) argue “one such construct receiving considerable attention for its potential to improve academic performance is student engagement” (p. 143). They claim engagement levels can predict favorable academic and behavioral outcomes in the classroom. Research by Yeung et al. (2010) agrees that student engagement levels in the classroom are known to be associated with learning outcomes. They argue that when students are engaged they “are likely to not only lead to better performances, but also influence their views of future opportunities and career aspirations” (p. 398). It is no secret that when students are cognitively engaged they are more likely to learn and improve academic performance. So who is in control of student engagement in the classroom?

Appleton and Lawrenz (2011) suggest that teachers are instrumental in shaping the level of engagement in the classroom. They argue teachers have an influential role in shaping the instructional context of the class which directly affects the level of student cognitive engagement. Their concern, however, is that there is a disconnect between teacher-perceived and actual student levels of engagement. Appleton and Lawrenz (2011) found that teachers perceived higher frequencies of student cognitive engagement when compared to actual student engagement with respect to the following:

a. Use of prior knowledge.

b. Class discussion.

c. Describing and reasoning.
The most significant differences between teacher perceived and student engagement levels were in real world problems and student use of prior knowledge (p. 150). The researchers state that the alignment of student and teacher perception is vital to ensure engaging contexts for students and higher academic gains. From my own experience teaching, I can attest that success in the classroom is largely attributed to knowing and understanding your student population. When there is a disconnect or lack of teacher-to-student rapport, students lose interest and consequently are not engaged in the learning process. Therefore teachers need to develop meaningful and positive relationships with students to understand their backgrounds, interests and strengths and weaknesses in the classroom. But even if you really know your student population, does that mean that all students, both boys and girls, are likely to be equally engaged in learning science?

Research by Yeung et al. (2010) surveyed 275 high achieving seventh grade students from Singapore about their perception of learning physics. The researchers found that boys and girls agree that it is important to know and understand physics in order to get a good job. Where boys and girls differ, however, is in their self-efficacy and career aspiration related to physics. According to the researchers, girls are less confident in their ability to learn and be successful in physics, and are less likely to want to pursue a career in physics. Girls make up half of the students in the science classroom; it is important that they are treated with equal learning opportunities with respect to boys. Teachers need to find ways to motivate and engage all students in the class, especially girls, so they are more likely feel confident and pursue careers in science (Yeung et al., 2010)

Other researchers have a different focus on engagement in public schools. Otieno and Wilder (2010) argue that in order to increase student engagement the entire community needs to be involved. Similarly, a case study by
Giles (2006) revealed how Durant High School was able to withstand tremendous educational reform through the 1970’s and 80’s by focusing on student-centered, community based-learning. Giles explained that it was not uncommon for Durant students to meet for class at a random location across the city; class was held where resources were readily available. Giles alluded to the fact that teachers had to be flexible in their schedule and teaching practices to accommodate for student interests. She claimed that because student engagement levels were so high the teachers and students were able to rally the community in support of preventing the board from closing the school on more than one occasion.

Otieno and Wilder (2010) noticed similar results of success and high engagement levels through promoting a partnership between middle school and local university. They constructed community-based teams that consisted of middle school students and teacher, a local university professor, and a graduate student or “fellow”. The teams worked to increase middle school interest, engagement, and achievement in math and science. The graduate fellow would work with the middle school teacher to adopt and modify existing non-inquiry-based activities to make them more inquiry-based.

The researchers found that inquiry-based activities seemed to engage students, particularly girls, to a greater extent than usual. This finding was extremely promising considering other researchers found that girls are less engaged in science than boys (Yeung et al., 2010). Furthermore, a survey of the 12 middle school teachers involved in the study revealed that “only one indicated that he saw no difference in student learning” (p. 14). Indeed, inquiry-based instruction could serve as an excellent instructional tool to get students engaged and interested in science.

**Inquiry learning and a comparison to traditional teaching.**

Recall earlier that Dean (2007) described inquiry as a method where students discover science through engaging experimentation. Like Dean, research by Cobern et al. (2010) believes the definition of inquiry “lies in ‘how students come to a concept’. That is, do students develop the concepts and principles from exploration, or are they told?” (p. 84). This is a good definition when determining the difference between direct instruction and inquiry. However, this definition assumes that there is only one concrete level of inquiry instruction. That is, instruction is
either direct or inquiry-based. Perhaps a more comprehensive definition of the term inquiry that identifies the varying levels and degrees of inquiry is more appropriate. Research by Blanchard et al. (2010) defines inquiry in levels:

- Level zero, or verification, where the source of the question, data collection methods, and interpretation of the results are all given by the teacher.
- Level one, or structured, where the source of the question and data collection methods are given by the teacher, but the interpretation of the results is open to the students.
- Level two, or guided, where the source of the question is given by the teacher, but the data collection methods and interpretation of the results is open to the students.
- Level three, or open, where the source of the question, data collection methods, and interpretation of the results are all open to the student.

This is a more comprehensive and appropriate definition of inquiry because it not only distinguishes the difference between direct and inquiry teaching (level zero versus levels one through three), but it also accurately characterizes different levels of inquiry as though they are not all equal. Now that we have a solid grasp on what inquiry is and how it may look in the classroom, the next essential question to ask is whether or not inquiry instruction should replace traditional teaching methods?

When evaluating the effectiveness of an instructional method, like inquiry, researchers must use true randomized experimental design and clearly defined levels of inquiry. Trochim (2006) states that in order for an experiment to be considered a true experiment, random assignment of test subjects must be used. Trochim further states that true randomized experiments are the strongest in establishing a causal assessment and maintaining internal validity. Experimental designs where there is a control group and experimental measures, but lack random assignment is considered quasi-experimental in design. He states that these experiments are inferior in design setup and lack internal validity.
It is difficult to *accurately* compare the effectiveness of inquiry and traditional instruction on student achievement on standardized tests because the vast majority of the literature is quasi-experimental in design. Why is finding research with appropriate methodology that compares instructional strategies so difficult to come across?

This is an on-going debate in the current literature regarding the “gold standard” in educational research. Many “hard-nosed” scientists feel that quasi-experimental studies are inferior in design, lack validity, and are hence inconclusive. On the other hand, parents, teachers and administrators are less accommodating to researchers coming into their school and randomly rearranging their student population to only offer a progressive educational practice to only a portion of the students. None the less, a truly experimental research article in the field of educational research is very difficult to come by.

One article, however, as according to Trochim (2006) and Pashler et al. (2009) did use appropriate methodology to compare inquiry and direct instruction in science. Research by Cobern et al. (2010) involved 180 8th grade students from rural, suburban and urban settings who took a course taught by veteran teachers for two weeks during the summer of 2007 and 2008. Student participation in the study was a family choice; but once students chose to participate, they were randomly assigned to both instructional methods groups. To maintain transparency and confirm validity, independent observers blind to experimental setup confirmed instructional methods of both groups. Conceptual understanding was measured using identical pre- and post-tests that consisted of 24 multiple choice questions that require students to apply conceptual knowledge rather than recall basic facts. This study is truly experimental in design, and maintains a high level of internal validity; so what did they find?

The students in Cobern et al.’s (2010) study were taught two different instructional units:

1. The dynamics of light, climate and seasons.
2. The dynamics of force, motion, mass their interrelationship with Newton’s Laws.
Results showed that there was not a statistically significant difference between student gains in instructional groups of the light unit (p=.451) and the Newton’s Laws unit (p=.474) (p. 91). Finally a study that is methodologically sound; yet it is inconclusive.

Evidently, the current literature does not have ample evidence to support that one instructional method is more effective; if the goal is to improve student performance on standardized tests. Further research with experimental methods like Cobern et al. (2010) need to be implemented before we can confidently answer which instructional method is more effective at improving test scores. So perhaps focusing on something besides test scores would be more appropriate?

**Inquiry and student engagement.**

Recall, it is critical for science teachers to keep their students cognitively engaged in science (Otieno and Wilder, 2010). If students are not interested and engaged in the material, they are not fully engaged in the learning process (Appleton and Lawrenz, 2011; Yeung et al., 2010). Mayer (2007) stated it best when he claimed “the kind of activity that really promotes meaningful learning is cognitive activity” (p. 17). Research by Maltese and Tai (2010) surveyed 116 PhD-track and active scientists, and found that “nearly 40% of the responses from the participants indicated that school-based factors played a key role in sparking their initial interest in science” (p. 681). Taking that into account, creating positive learning experiences in the science classroom should be the more appropriate focus when assessing which instructional method is more appropriate. Recall, the number of students who want to pursue careers in math and science is diminishing (Dean, 2007). Shouldn’t we be more focused on finding an instructional method that creates a more positive and engaging learning environment; and not just better test scores?

Research by Wang and Lin (2009) quantitatively and qualitatively analyzed elementary and secondary school learning environments in Taiwan. They found that elementary students enjoyed science and were found to be more interactive and engaged in their classrooms when compared with middle school students. Student interviews revealed that elementary students were primarily motivated by interaction and the investigation of science in the classroom. Similarly, research by Kur and Heintzmann (2008) found that when taking an inquiry approach towards
learning about magnets elementary students “mastered the concepts of the unit” (p. 32). They also found that using scientific inquiry “empowered our students to become scientists” (p. 32). Clearly it seems as though elementary students may benefit greatly from an inquiry approach to learning, but is this still the case with older students?

Wolf and Fraser (2007) compared inquiry and non-inquiry instruction and its effect on student attitudes in the middle school science classroom. Like research by Wang and Lin (2009) and Kur and Heintzmann (2008), Wolf and Fraser found that inquiry instruction “promoted more cohesiveness than non-inquiry instruction” (p.17). Furthermore, research by Lord and Orkwiszewski (2006) found college-level freshman experiencing the same thing. They found that overall students that were taught through inquiry-based methods had better attitudes towards science than students learning through didactic instruction. Students in Lord and Orkwiszewski were quoted saying “I never realized how much fun it was to discover science like real scientists do”. Others stated “What a terrific way to learn, why don’t all the profs teach this way?” (p. 345).

It appears that despite the level of schooling, elementary, secondary or college, inquiry instruction fosters a cohesive, engaging and positive learning environment in science classrooms. Anyone who wants to take an evidence-based approach to educational practice should view inquiry as a necessary and integral component not designed to improve traditional test scores; but to spark interest and motivate young minds to analyze, think critically, and uncover science phenomena.

**Evidence-based writing and argumentation.**

Getting students engaged through inquiry based lessons is an excellent strategy to get students asking questions, thinking critically and problem solve in the classroom, but what good are these skills in college or the real-world if students can’t put their knowledge down on paper to make an evidence-based claim or argument? Recall that the scientific literacy skills of students in American schools today is lacking. This is no secret amongst scholars. Researchers have focused a lot of attention on students and what skills they are learning in science class; specifically their ability reason, argue and make evidence-based claims in a scientific discussion. As Brown et al. (2010) point out “The creation of learning environments that develop students’ abilities to reason from evidence and participate in
science argumentation is considered a major priority in science education reform” (p. 123). Like Brown et al., research by McNeil (2009) agrees that explanation and argumentation are core practices of scientists. She explains, “Science is not about discovering or memorizing facts; rather it is about constructing arguments and considering and debating multiple explanations for phenomena” (p. 234). Today’s society is flooded with all sorts of mass media claims and assertions. All individuals, not just scientists, need to apply the same critical skills of science argumentation and evidence-based reasoning for personal decision making, participation in societal affairs, and financial stability.

It is unlikely that all students will become scientists. What is more important, rather, is that all students become consumers of science. Brown et al. (2010) explain “to be well-balanced and intelligent consumers of scientific information students must understand that there should be ample evidence present to determine whether hypotheses are valid” (p. 124). They argue that this critical skill is crucial for students to develop a more complete and deeper understanding of the natural world around them. It is no surprise that the National Research Council publication Taking Science to School: Learning and Teaching Science in Grades K-8 (Duschl, Schweingruber, and Shouse, 2006) agrees that students should be able to “Generate and evaluate scientific evidence and explanation” (p. 2). Clearly evaluating evidence to engage in scientific argumentation is a critical skill for students in the science classroom, but how do we get students to attain such a goal?

There are a number of strategies scholars suggest for engaging a classroom of students in meaningful scientific argumentation. One such method receiving a lot of attention is through the effective use of a writing task. McNeill (2009) suggests “The way a teacher frames a scientific argumentation writing task influences the product that students produce” (p. 236). More specifically, research by Dawson and Venville (2010) found a great deal of success observing a teacher who used “writing frames” in the classroom. The writing frames consisted of a series of questions that were designed to encourage students to make a decision and to articulate reasons for their decision. For example, how would you convince someone who disagreed with you? Or what would you need to know to make your argument stronger? These types of questions, Dawson and Venville explained, encouraged students to “use data, warrants and make explicit the underlying assumptions (backings) that supported their claims” (p. 144).
Another useful strategy to involve students in scientific argumentation is through the effective use of whole-class discussions. Dawson and Venville (2010) also found that whole class discussions can be an excellent way to engage the entire class. They observed an exemplar teacher who asked questions to the entire class and would rephrase or restate the student comments so everyone could hear. He would build on the student responses by adding more evidence to the scenario, or by playing devil’s advocate. Often, the teacher would encourage students to answer each other’s questions and he would remain the intermediary. This is contrary to traditional classroom discourse pattern. McNeil (2009) claims that traditional science classrooms consist of a teacher initiating a question, students respond, and then the teacher evaluates the response. McNeil also observed an exemplar teacher who was able to effectively engage her students in meaningful science argumentation through whole-class discussion. The teacher encouraged students to answer each other’s questions. McNeil claims “The student initiative in this conversation suggests that they had taken ownership and understood how to critique the scientific explanations” (p. 254). When students are able to take ownership of the ideas in class they begin to construct their knowledge and make deeper and more meaningful connections to the science content and argumentation process.

An important consideration teachers need to keep in mind when developing lessons that promote science argumentation is to keep the content interesting and “doable”. To effectively engage the student body in meaningful discussion and argumentation students need to be interested and able to understand the context. Dawson and Venville (2010) explain that it is important that the socioscientific issues be set in a context where students are able to apply their newly acquired knowledge. Like Dawson and Venville, Lewis (2000) and Aufschnaiter et al. (2008) both state that students must have prior scientific knowledge in order to successfully engage in science argumentation. Not only do the students need to have prior knowledge, but the socioscientific issues being discussed should be interesting and fun. When students can relate to the material and make personal connections to the context their engagement in the argumentation process becomes much more evident. Teachers should strive to develop lessons that promote argumentation around current, relevant and interesting socioscientific dilemmas that requires students to pull from and build upon prior knowledge.
Chapter 3: Capstone Project

Project Design

This project is designed to be an organized collection of inquiry-based labs and activities in AP Biology that promote opportunities for evidence-based writing. The project will consist of at least 16 labs and/or activities that will be organized in a timeline according to my AP Biology curriculum calendar. Each lab will include the following, as applicable:

- Title
- Objectives
- AP Biology Standards/Enduring Understandings
- Materials
- Background information and prior knowledge required to successfully comprehend and complete the lab or activity.
- Possible misconceptions/typical concepts students often struggle with.
- A reflection of how the lab/activity went. What went well, what could change or be done better? (when applicable)

The intent of this project is to create a “cookbook” of lessons that will help adjust to the new curriculum and direction the College Board is headed with AP Biology.

Significance of Project

There a couple of reasons why this project is of particular significance. First, as described in the literature review, the College Board is taking a new direction with their curricular standards. They have switched their focus from scope of knowledge to depth and application of knowledge. The College Board intends to develop an AP Biology curriculum
and culminating exam that encompasses student-centered, inquiry-based learning that promotes critical thinking, problem solving, and scientific skills. Secondly, New York State has also taken a new educational initiative with the implementation of the Common Core State Standards (CCSS). One of the major shifts the CCSS calls for is higher literacy standards across all subject areas. This project will help to address these changes. It will help the classroom become more student-centered, and engaging. Class activities will require students to ask questions, think critically, and seek out their own answers using scientific reasoning. Students benefitting from this project should be able to utilize their evidence to make conclusions and arguments about scientific phenomena. Lastly, this project will help teacher instruction to be more in tune with the state and national standards set forth by the College Board and NYS Board of Education.

Definition of Key Terms

**Engagement** - a commitment to, valuing of, and connection with the people, educational goals, and outcomes promoted by a school.

**Inquiry** – an instructional method where students ask questions and discover the concepts and principles from exploration, rather than being told.

**Advanced Placement Biology** – a college-level course offered by the College Board to advanced high school students who want to earn college credit prior to formally entering post-secondary school.

**Science Literacy** – an evolving combination of the science-related attitudes, skills, and knowledge students need to develop inquiry, problem-solving, and decision-making abilities, to become lifelong learners, and to maintain a sense of wonder about the world around them.
Lab Investigation: Why are Cells Small?

Background

Have you ever wondered why cells are so small? Why they are not the size of a book or a car? In this lab, you will discover, quantitatively, why their size is limited by the processes that take place in the cell.

It is through the cell membrane that food, gases, and water enter the cell, and waste products leave the cell. How quickly this exchange takes place depends on the surface area of the cell membrane. The amount of food and oxygen needed and the amount of waste produced depends on the volume of the cell. When cells grow to a certain size, their rate of growth slows down and then stops. They have reached their size limit. When one of these larger cells divides into two smaller cells, the rate of growth increases again. In this activity we are going to create model cells of different sizes and see which one is most efficient at exchanging materials.

Even though most cells are not shaped like cubes, the mathematics involved with surface area and volume are simpler for cubes than for other shapes so will we assume the cell is cube shaped today.

Objectives/Learning Standards

The student is able to use calculated surface area-to-volume ratios to predict which cell(s) might eliminate wastes or procure nutrients faster by diffusion (2A3 & SP 2.2).

The student is able to explain how cell size and shape affect the overall rate of nutrient intake and the rate of waste elimination (2A3 & SP 2.2).

The student is able to use representations and models to analyze situations or solve problems qualitatively and quantitatively to investigate whether dynamic homeostasis is maintained by the active movement of molecules across membranes (2B1 & 2B2 & SP 2.2, SP 5.2, SP 5.3).

Materials

-Agar containing phenolphthalein  -metric ruler
-0.1 M NaOH  -razor blade

Misconceptions/Student Struggles

Students struggle at scientific inquiry when they are not provided with procedural guidance. To address this a brief demonstration that models diffusion and the agar cubes changing color when placed in a basic solution is necessary. It is important to demonstrate that the cubes can be cut open to see how much
solution diffused into the cube. The other part students typically struggle with is the math calculations and data table setup. To address this issue, encourage students to work together and think about the big picture. Such as, how can I quantitatively determine which cell is most efficient at transporting materials inside and outside the cell?

**Hypothesis**

Predict which cell will exchange materials inside and outside the cell the most efficiently. Provide scientific reasoning for your prediction.

*Having students generate a rich hypothesis immediately places the student in the driver seat. They begin to think critically, reason scientifically and immediately become engaged in the lesson. They start to become in control of their own learning. This helps create an engaging atmosphere that promotes active learning in the classroom [Yeung et al. (2010), Otieno and Wilder (2010), Mayer (2007)].*

**Procedure**

1. Watch a brief demonstration from your teacher. 
   *Modeling is a great way to address misconceptions. Research by Dawson and Venville (2010) emphasized the importance of science activities and tasks being “doable”. Modeling is a great way to achieve just that.*

2. Cut three blocks of agar into cubes of different sizes. Try your best to be as precise as possible when making sure that all sides are of equal length. Use a metric ruler to help.

3. Design an experiment with your classmates to determine which cube, or “cell”, is most efficient at transporting materials inside and outside the cell. Check your procedure with your teacher before beginning.
   a. Some questions to consider...
      i. What is the surface area of each of your three blocks?
      ii. What is the total volume of each of your three blocks?
   *Having students cut up cubes to sizes of their own choosing, and then designing and experiment on their own is a student-centered inquiry-based activity. The guiding questions will lead them in the direction to be successful, but students will have to work together to figure out the best way to quantitatively determine which cell is most efficient at transporting materials. Students will need to control several factors such as the amount of time each cube is submerged, the depth under the solution that each cube is submerged, the strength of the solution used when submerging the cubes, etc. Students will also have to work together to figure out the mathematics involved in determining which cell is most efficient. This type of inquiry learning promotes critical thinking skills and improved attitudes towards science [Otieno and Wilder (2010), Kur and Heintzmann (2008), Wolf and Fraser (2007), Lord and Orkwiszewski (2007)].*

4. Setup a data table to record your data and calculations. This will be turned in with your lab report.
Discussion/Conclusion

Discuss your results and explain what you learned from this lab investigation. Be sure to do the following:

1. Reference your original hypothesis.
2. Use the data to make your claims and let the data speak on your behalf.
   a. *Hint* - Imagine if someone disagreed with your conclusion about which cell is most efficient, how could you persuade him otherwise? What evidence would make your argument stronger than his?
3. Explain your claims with scientific reasoning.

This section encourages students to interpret the evidence and use it to make a scientific claim and/or argument. This type of activity is not only a required skill of the CCSS shifts, but it helps create a classroom where the students become true “consumers of science” [Brown et al. (2010), McNeil (2009), Dawson and Venville (2010), Duschl, Schweingruber and Shouse (2006)]. The discussion prompts helps frame the writing task. This, as McNeil (2009) and Dawson and Venville (2010) point out, encourage students to use and interpret data, and argue scientifically.

Rationale for Change

This lab is an improvement for a couple of reasons. First the initial teacher demonstration helps address misconceptions and struggles that students typically have. It also has an important introduction with appropriate background knowledge to setup students for success. Lastly, this version provides an opportunity for students to generate a hypothesis and refer back to it by referencing their data at the end of the lab. This allows students to make evidence-based claims which encourage scientific reasoning and argumentation. Making evidence-based claims is a skill heavily demanded for by the new CCSS initiative.
Testing Enzyme Catalase Activity

Background

Potato and other living tissues contain the enzyme catalase. This enzyme breaks down hydrogen peroxide, which is a harmful by-product of the process of cellular respiration if it builds up in concentration in the cells. The reaction is described by the following equation.

\[ 2 \text{H}_2\text{O}_2 \rightarrow 2 \text{H}_2\text{O} + \text{O}_2 \]

If we use potato or other tissue containing this enzyme, we can use this to measure the relative influence of varying several different factors on the activity of enzymes in living tissue.

Objective

To determine how environmental factors such as temperature, pH and concentration affect the rate of enzymatic activity.

Hypothesis

Brainstorm with your teacher and fellow classmates a list of environmental factors that could affect enzyme activity. Choose one factor to investigate and write your hypothesis below. Be sure to identify the enzyme, substrate and products in your hypothesis.

Ex) I hypothesize that... (explain what you think will happen) because... (explain why you think that will happen – include biological concepts).

*hypothesis can be very specific or they can be focused on overall trends. The key is to be clear and concise and include a thorough explanation of WHY*

Having students write their own hypothesis helps create an engaging atmosphere that promotes active learning in the classroom [Yeung et al. (2010), Otieno and Wilder (2010), Mayer (2007)]. This is also one of the first labs in the curriculum where students have to make a formal hypothesis. Providing detailed instructions with an example is helpful so that students will be successful at writing their hypothesis for not only this, but also the rest of the labs throughout the year. Being able to write well thought out hypothesis is a skill set that will build a classroom of students that are consumers of science [Brown et al. (2010), McNeil (2009), Dawson and Venville (2010), Duschl, Schweingruber and Shouse (2006)].

Materials and Supplies
Independent Variable/Manipulated Variable: ________________________________________________

Many students choose pH, or temperature, or concentration. Experimenting with these variables will challenge students' science literacy skills because students have to problem solve to learn how to maintain a constant temp for a water bath, or figure out the math to make different concentrations of enzyme, etc. This type of inquiry learning promotes critical thinking skills and improved attitudes towards science [Otieno and Wilder (2010), Kur and Heintzmann (2008), Wolf and Fraser (2007), Lord and Orkiszewski (2007)].

Controlled Variables/Variables Held Constant: ________________________________________________

Methods

In this lab you and your lab partner are going to use a Vernier LabQuest and gas pressure sensor to measure the rate of enzymatic activity in kPa/sec. Watch a brief demonstration by your teacher and then use the space below to write down your step-by-step procedure for conducting your experiment. Use an extra sheet of paper if necessary.

This lab is very much a hands-on lab that allows students to work with real enzymes and substrates. When they combine the enzyme (catalase) and substrate (hydrogen peroxide) they can literally see the fizzing reaction. Even better, using a Vernier LabQuest, they can quantify the reaction in pressure build-up over time.
This lab also allows students the opportunity to create and design their own investigation. Students make predictions and learn to setup a controlled experiment that scientifically investigates their questions about enzyme activity. Students learn to control and manipulate variables, and collect and interpret data. These are all required skills of the AP Biology curriculum framework and promote a student-centered, hands-on and engaging inquiry approach to learning science [Otieno and Wilder (2010), Kur and Heintzmann (2008), Wolf and Fraser (2007), Lord and Orkwiszewski (2007)].

Results

Setup a table on a separate piece of paper (or on the computer) to record your data. You will also use the data in your table to create a graph illustrating how the rate of enzymatic activity is influenced by your independent variable.

Students record pressure in kPa over time and calculate rates of reaction by hand using the mathematical formula for calculating rates. Knowing how to calculate the rate of a reaction is a required skill from the AP Biology curriculum.

Discussion

Analyze your data and graphs to formulate a conclusion about how your independent variable affects the rate of catalase activity. Use and specifically reference your data in your discussion to support your claims. Be sure to thoroughly explain the biological concepts involved. For example, be sure to explain why the rate catalase activity changed as a result of your independent variable. Use the following format when writing your discussion:

Many high school students do not know how to write scientifically. More specifically, students struggle at using evidence to support their claims. Many students are able to explain the overall concept of the lab and the biological processes involved, but they struggle at incorporating hard evidence to validate their conclusions. This lab provides students with quantitative evidence that they can use to support their conclusions about enzyme activity. The discussion prompts and exemplar will help students use and interpret data, argue scientifically and develop science literacy [Brown et al. (2010), McNeil (2009), Dawson and Venville (2010), Duschl, Schweingruber and Shouse (2006)].

1. **Claim** about your independent variable affecting rate of enzyme activity
   a. **Support** with evidence/data from your graph or data table
      i. Provide further explanation about the biological concepts involved.
         - NEW PARAGRAPH -

2. Repeat

Ex) I originally hypothesized that enzymatic activity would work best in an acidic pH. Our data did not support my hypothesis. We found that as pH increases enzyme activity increases, peaks around a neutral pH, then decreases as pH continues to rise (**CLAIM**). At a pH of 1 the rate of reaction was 0 kPa/s. As pH was increased to 7 the rate of reaction peaked as .25 kPa/s. As pH was further increased to 10 the rate of reaction, as expected, decreased to 0.03 kPa/s (**SUPPORT**). According to Campbell & Reece (2005) and our class notes too acidic and basic pH disrupts the
peptide bonds of proteins which changes their shape and results in the proteins becoming denatured and dysfunctional. Enzymes are made of protein and in a strong acid or base I would have expected the enzyme to denature and have a minimal or no rate of reaction. At neutral pH, most enzymes work best. Our data suggest that catalase, like most enzymes, also works best at a neutral pH (**EXPLANATION**).

*Even with detailed instructions, students still struggle with writing tasks. Providing students with an exemplar really sets up the student for success. In the AP Biology curriculum, this is one of the first labs of the year where students write up a formal discussion so providing an exemplar will be very helpful [McNeil (2009) and Dawson and Venville (2010)].*
Cell Respiration Lab

Background

Living systems require free energy and matter to maintain order, to grow, and to reproduce. Energy deficiencies are not only detrimental to individual organisms, but they cause disruptions at the population and ecosystem levels as well. Organisms employ various strategies that have been conserved through evolution to capture, use, and store free energy. Autotrophic organisms capture free energy from the environment through photosynthesis and chemosynthesis, whereas heterotrophic organisms harvest free energy from consuming carbon compounds produced by other organisms. The process of cellular respiration harvests the stored energy in organic carbon compounds to produce ATP, the molecule that powers most of the vital cellular processes. In eukaryotes, respiration occurs in the mitochondria within cells.

If sufficient oxygen is available, glucose may be oxidized completely in a series of enzyme-mediated steps, as summarized by the following reaction:

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2(\text{g}) \rightarrow 6\text{CO}_2(\text{g}) + 6\text{H}_2\text{O} + \text{energy (686 kilocalories)}
\]

In this lab investigation you will use O₂ sensors to measure the rate of respiration in germinating peas. What are some factors that could affect the rate of respiration?

This lab has been adapted from one of the 13 required AP Biology labs. One of the difficulties with the College Board version of this lab is that the method for measuring respiration is accomplished by measuring a change in volume over time (as the peas consume oxygen the volume of the container should decrease and move a red dye across a capillary tube. The model takes a lot of time to setup but works well at room temperature. If a student wants to investigate how temperature affects respiration in germinating peas, however, then the model won’t work well because temperature, pressure and volume are all affected by each other in the combined gas law. Therefore, using the Oxygen sensors that detect Oxygen concentration only allows students to manipulate more variables in this lab – plus it takes much less time to setup.

Hypothesis

Brainstorm with your teacher and classmates some ideas of factors that could affect the rate of respiration. Choose one factor to investigate and write your hypothesis below.
Materials and Supplies

Generate a list of materials and supplies that you will need to conduct your experiment.

Independent Variable/Manipulated Variable: ______________________________________________

Controlled Variables/Variables Held Constant: ____________________________________________

Methods

Use this space to write down your step-by-step procedure for conducting your experiment. Use an extra sheet of paper if necessary.

This lab is very similar to the previous lab on investigating the enzymatic activity of catalase. Respiration requires several enzyme-catalyzed reactions so the variables that affect the rate of respiration are very much the same as the variables that affect enzyme activity in the previous lab. Therefore, in this lab the goal is to push students to think outside the box. For example, you could get many different kinds of seeds to germinate and have students compare respiration rates between the different seeds types and try to come up with explanations why. You could also bring in crickets and have students measure the respiration rate of crickets. This is often fun for students because they learn to handle living animals and students typically enjoy observing their behaviors. One of the variables that is crucial for students to investigate is how temperature affects the rate of respiration; there are several learning objectives that relate to this concept. Because crickets are ectotherms (cold-blooded) their metabolic activity and respiration rates decreases with colder temperatures. Students are able to not only measure this quantitatively (in oxygen consumed over time) but observe it with their eyes. When the crickets are placed in cold temperatures their ATP production slows down so much that they stop moving and become inactive. This type of science activity is not only inquiry-based in design, but very engaging which helps improve attitudes towards science [Otieno and Wilder (2010), Kur and Heintzmann (2008), Wolf and Fraser (2007), Lord and Orkwiszewski (2007)].
Results

Setup a table on a separate piece of paper (or on the computer) to record your data. You will use the data in your table to also create a graph illustrating the effects of your independent variable over time.

_The key here is to have students graph their oxygen consumption over time. One of the skills required in the AP Biology standards is to be able to interpret data displayed in a graph. Students need to know that rates, when graphed over time, have a slope, and the steeper the slow the greater the reaction. The students also need to be able to recognize the difference between oxygen concentration and rate of oxygen consumption. The AP will represent graphical data many different ways and students need to be able to recognize, interpret and draw conclusion from that. Being able to interpret data graphically is one of the many skills of a scientists, which when practiced helps develop science literacy in the classroom [Brown et al. (2010), McNeil (2009), Dawson and Venville (2010), Duschl, Schweingruber and Shouse (2006)]._

Discussion

Analyze your data and graphs to formulate a conclusion about how your independent variable affects the rate of respiration in peas (or other organism you may have chosen). Use and specifically reference your data in your discussion to support your claims about respiration. Be sure to thoroughly explain the biological concepts involved. For example, be sure to explain _why_ the rate of respiration changed as a result of your independent variable. Use the following format when writing your discussion:
1. **Claim** about your independent variable affecting respiration
   a. Support with evidence/data from your graph or data table
      i. Provide further explanation about the biological concepts involved.

   Ex.) As temperature increases, the rate of respiration in peas increases then decreases (CLAIM). For example, when the temperature was 1°C the rate of oxygen consumption was 200 ppm/min/50peas. As temperature increased to 25°C the rate of oxygen consumption rose to 500 ppm/min/50peas. At an even higher temperature of 100°C the rate of oxygen consumption, however, decreased to 6 ppm/min/50peas (EVIDENCE). Cellular respiration is a very complex biological process that involves several enzyme-mediated reactions that harvest the stored chemical energy found in carbon compounds such as glucose. In respiration, oxygen is required to oxidize glucose into ATP. As more oxygen is consumed, the rate of cellular respiration will increase. At lower temperatures, less oxygen is consumed because the collisions between enzymes involved with cellular respiration and substrates slow down. As temperature increases, the rate of respiration increases because more kinetic energy allows enzymes and substrates to collide more frequently. When temperature rises too much, above 37°C, there is too much kinetic energy which causes enzymes to denature. When enzymes denature, the bonds between amino acids break apart causing the enzyme to unravel, change shape and no longer work. This is why the rate of oxygen consumption was very low at 100°C (FURTHER EXPLANATION).

This is another lab early on in the year where students are still learning how to write scientifically. They are still working on their skills of writing with evidence. By the time they get to this lab the previous enzyme lab should be graded and handed back with comments. It is important to provide as much constructive feedback as possible in their last lab so that they can improve upon that for this lab and further their science literacy skills [Brown et al. (2010), McNeil (2009), Dawson and Venville (2010), Duschl, Schweingruber and Shouse (2006)]. As research by Dawson and Venville (2010) point out, science activities and writing tasks must be “doable”. Providing cool and warm feedback, as well as another exemplar discussion will also help them to be successful and using evidence to support their claims.
Photosynthesis Lab

Background

The process of photosynthesis occurs in a series of enzyme-mediated steps that capture light energy to build energy-rich carbohydrates. The process is summarized by the following reaction:

\[ 2 \text{H}_2\text{O} + \text{CO}_2 + \text{light} \rightarrow \text{carbohydrate (CH}_2\text{O}) + \text{O}_2 + \text{H}_2\text{O} \]

To determine the net rate of photosynthesis, one could measure one of the following:

• Production of O₂
• Consumption of CO₂

The difficulty related to measuring the production of oxygen is compounded by the complementary process of aerobic respiration consuming oxygen as it is produced. Therefore, measuring oxygen production is equivalent to measuring net photosynthesis. A measurement of respiration in the same system allows one also to estimate the gross production.

Generally, the rate of photosynthesis is calculated by measuring the consumption of carbon dioxide. However, equipment and procedures to do this are generally beyond the reach of most introductory laboratories. In this lab we are going to utilize a much easier process where we will punch out small disks of spinach, or other plants, and sink them in a bicarbonate solution that contains dissolved CO₂. We will shine a light source onto the sunken disks. As they photosynthesize and produce O₂ bubbles, we will measure the time it takes for the disks to rise.

This lab is also adopted from the AP Biology lab manual. The procedure of measuring the rate of photosynthesis by sinking plant leaf disks and measuring the time it takes for half of them to rise is taken from the AP Biology lab manual. This lab, as Dawson and Venville (2010) point out, is “doable” because it is very easy to setup, easy to observe, and does not require fancy expensive equipment like a spectrophotometer. This lab also provides an opportunity to take it a step further and put the students in the driver seat. There are several factors that can affect the rate of photosynthesis so have students setup and design their own experiment. This will create an engaging atmosphere that promotes active learning in the classroom [Yeung et al. (2010), Otieno and Wilder (2010), Mayer (2007)].
Hypothesis

Brainstorm with your teacher and classmates some ideas of factors that could affect the rate of photosynthesis. Choose one factor to investigate and write your hypothesis below.

_______________________________________________________________________________________________
_______________________________________________________________________________________________
_______________________________________________________________________________________________
_______________________________________________________________________________________________

Materials and Supplies

Generate a list of materials and supplies that you will need to conduct your experiment.

Independent Variable/Manipulated Variable: ________________________________________________

There are several options here but most students pick different colors of light, different distances from the light, different angles that light strikes the leaf disks, different CO2 concentrations, etc. Many students may also like to try this with different types of leaves. They can go outside, pick leaves, and compare how leaves on the ground compare to leaves still attached to the tree. They can compare leaves of different color. There a ton of possibilities here which again, puts the student in the driver seat and forefront of the learning process [Otieno and Wilder (2010), Kur and Heintzmann (2008), Wolf and Fraser (2007), Lord and Orkwiszewski (2007)].

Controlled Variables/Variables Held Constant: ________________________________________________
Controlled variables are particularly important here because so many factors affect photosynthesis. For example, if students are measuring photosynthesis at different distances from the light source, then they also need to be sure to control the angle of light exposure, or vice-versa. Or if students are measuring how different color lights affect the rate of photosynthesis they have to try their best to reduce ambient light from the classroom. Controlling for these factors promotes critical thinking skills that are crucial to developing science literacy [Dillon (2009), Their (2010), CCSS Initiative (2011)].

Control Group: 

Methods

Yesterday in class you learned how to perform the sinking leaf disks method to measure photosynthesis. Use the same method to measure the rate of photosynthesis, as affected by your independent variable. Write your step-by-step procedure below.

This lab builds upon the sinking leaf disks method learned in the previous lab to further extend their learning and science literacy skills. As Dawson and Venville (2010), Lewis (2000), and Aufschnaiter et al. (2008) point out, students must have prior knowledge to be engaged in learning science.
**Results**

Setup a table on a separate piece of paper (or on the computer) to record your data. Your data table must include your independent variable, $ET_{50}$ and the rate of photosynthesis ($\cdot$). Include a graph that illustrates how the rate of photosynthesis ($\cdot$ in $1/ET_{50}$ for units) is affected by your independent variable.

*The key here is for the independent variable to be quantitative. Graphing this way will allow another opportunity for students to visualize and interpret their data graphically. Being able to analyze and interpret data and evidence is an important science literacy skill [Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006)].*

**Discussion**

Analyze your data and graphs to formulate a conclusion about how your independent variable affects the rate of photosynthesis. Use and specifically reference your data in your discussion to support your claims about photosynthesis. Be sure to thoroughly explain the biological concepts involved. For example, be sure to explain why the rate of photosynthesis changed as a result of your independent variable. Use the following format when writing your discussion:

1. **Claim** about your independent variable affecting respiration
   a. Support with evidence/data from your graph or data table
      i. Provide **further explanation** about the biological concepts involved.

*This is yet another opportunity where students are able to use their data as evidence to support their claims about photosynthesis. Like the previous labs, the discussion prompts encourage science argumentation which according to Dawson and Venville (2010), Brown et al. (2010), and McNeil (2009) is an important and core practice of science.*
Understanding Mitosis

Background

It was first discovered in 1858, by Rudolf Virchow, that new cells can only arise from previously existing cells. This is done in two ways: mitosis, or meiosis. Somatic (body) cells divide exclusively though mitosis and cytokinesis, while germ cells produce gametes (sex cells) through meiosis. The process of mitosis in plants, however, is carried out a little bit differently. Plant cells simply enlarge over time, by absorbing water. When they reach a certain size, they divide, forming two identical daughter cells. The various parts of the cells are divided in such a way that the new daughter cell is identical to the parent cell. Refer to your notes for the specific steps and processes involved in mitosis and cytokinesis and how they differ between plants and animals.

Procedure

1. Go to the website:
   a. www.biology.arizona.edu/cell_bio/activities/cell_cycle/assignment.html
2. Read the directions.
3. Click “Next” at the bottom of the page.
   a. Note - When it says to copy the data table to a piece of paper, you do not have to. Use the one below.
4. For each cell pictured, click on the stage of mitosis it belongs in. Each correct placement should be tallied with a mark in the appropriate box below.
5. Continue through the whole activity keeping track of your tallies.
6. When finished make the necessary calculations. Place your answers in the appropriate box below. Round percentages to the nearest tenth.
7. Assume that an average onion root tip cell cycle is 24 hours long, or 1,440 minutes. Calculate the amount of time (in minutes) cells typically spend in each phase.

<table>
<thead>
<tr>
<th>Interphase</th>
<th>Prophase</th>
<th>Metaphase</th>
<th>Anaphase</th>
<th>Telophase</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td># of Cells</td>
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<tr>
<td>% of Cells</td>
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<tr>
<td>Minutes spent per day</td>
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</table>
This lab is a modified version of one of the required AP labs. The original AP lab requires students to grow onion root tips, and make a prepared slide from those onion root tips to observe the cells in the difference phases of mitosis. This is a very difficult task to complete successfully. Another difficulty with this lab is that students struggle at identifying the phases of mitosis under a microscope without practice first. Therefore, use of this website where students look, one picture at a time, and determine what phase the cells are in is a helpful tool to build confidence and fundamental skills in recognizing cells in different stages of mitosis. If the students are incorrect, the website gives them a clue as to why and makes them try again until they get it right. This helps students practice and builds prior knowledge before they use microscopes on their own. This as Dawson and Venville (2010), Lewis (2000), Aufschnaiter et al. (2008) point out is a necessary skill to be successful in the science classroom.

This lab also requires students to calculate the percent of cells in each phase. One of the skills required in the AP Biology curriculum is for students to be able to mathematically calculate percents and use those percents to make conversions. In this lab students have to first calculate the % of cells in each phase, and then convert that % to time or minutes per day which requires setting up a mathematical proportion. Using math to convert and analyze data is another skills students must learn to promote a population of critical thinkers and consumers of science [Dillon (2009), Their (2010), CCSS Initiative (2011)].

Analysis Questions

1. Why are most of the cells in interphase? Explain.

_______________________________________________________________________________________________
_______________________________________________________________________________________________
_______________________________________________________________________________________________
_______________________________________________________________________________________________

2. Why are so few cells in anaphase and telophase? Justify your answer.

_______________________________________________________________________________________________
_______________________________________________________________________________________________

3. Sketch a pie graph illustrating the percentage of time cells spend in each phase of mitosis. Be sure to label your graph accordingly. Draw it to scale using a protractor.
4. Compare and contrast the processes of mitosis and cytokinesis.

_______________________________________________________________________________________________
_______________________________________________________________________________________________
_______________________________________________________________________________________________
_______________________________________________________________________________________________

5. Which of the following is significantly different between plant and animal cell mitosis? Explain your answer.
   a. Metaphase
   b. Anaphase
   c. Cytokinesis
   d. Prophase

_______________________________________________________________________________________________
_______________________________________________________________________________________________
_______________________________________________________________________________________________
_______________________________________________________________________________________________

6. Complete the following graph. On the x-axis write in the phases of mitosis in order. When the line for the amount of genetic material changes in height, indicate with an arrow the event that took place (replication, separation of chromosome, etc.). With a second color sketch the diversity of the genetic material present within a cell. Include a key.

Relative Amount of Genetic Material

-OR-

Diversity of Genetic Material

Time

This analysis question requires students to really apply their knowledge and understanding of mitosis. Students understand the process of mitosis in a time-line of events, but can they take their knowledge of the timeline and represent it in another format? This graph is a challenge to do just that. A common struggle for students is that when
DNA replicates at the beginning of mitosis, they struggle to realize that although there is twice as much genetic information, no new information has been created.
Picturing Mitosis

Background
Mitosis is the process by which a cell separates its duplicated genome into two identical halves. It is generally followed immediately by cytokinesis which divides the cytoplasm and cell membrane. This results in two identical daughter cells with a roughly equal distribution of organelles and other cellular components. Mitosis and cytokinesis together define the mitotic (M) phase of the cell cycle, the division of the mother cell into two daughter cells, each with the genetic equivalent of the parent cell. Mitosis occurs exclusively in eukaryotic cells. In multicellular organisms, the somatic cells, non-sex cells undergo mitosis.

The process of mitosis is complex and highly regulated. The sequence of events is divided into phases, corresponding to the completion of one set of activities and the start of the next. These stages are prophase, metaphase, anaphase and telophase. During the process of mitosis the pairs of chromosomes condense and attach to fibers that pull the sister chromatids to opposite sides of the cell. The cell then divides in cytokinesis, to produce two identical daughter cells.

Materials
mitosis pictures  scissors  glue

Objectives
1. Arrange the phases of mitosis in the correct order based on diagrams
2. Identify specific structures involved in mitotic cell division
3. Compare mitosis in plant and animal cells

Procedure
1) Look at the cards on page 3 showing the different stages of mitosis.

2) Cut out the pictures and tape them to your answer sheet in the correct order.

3) Use the following words to name each of the pictures on your answer sheet.
   Interphase G1, Early Prophase, Middle Prophase, Late Prophase, Metaphase, Early Anaphase, Middle Anaphase, Late Anaphase, Early Telophase, Late Telophase, Interphase G1

4) Complete the questions below related to the pictures.

This lab is a modified version of one of the AP Biology required labs. The required lab calls for students to model mitosis. Constructing, modifying, and interpreting models is a science practice required in the AP Biology curriculum. This learning activity also allows students to construct a model of mitosis, however it is setup with pictures that scaffold the modeling process. Research by Dawson and Venville (2010) emphasized the importance of science activities and tasks being “doable”. This is an introductory learning activity that helps to improve student learning, and build confidence through repetition. This lab will also help the student establish and build upon prior knowledge [Dawson and Venville (2010), Lewis (2000), Aufschnaiter et al. (2008)].

Analysis
1. The absence of centrioles identifies the cells as _________________ cells.
2. The presence of border X also identifies the type of cell shown. X is the ________________.

3. Picture _____ is the first picture to show chromosomes with their copies. (Look carefully)

4. Y in picture C is the ____________________.

5. The type of cell division illustrated in the pictures is ________________.

6. Structure Z is knows as the ____________________.

Review Questions

1. The diagrams below represent two different cells undergoing mitotic cell division.

A. [Images of cell division stages]

B. [Images of cell division stages]

Which statement about these divisions is true?
A) Division A could occur in a bean plant and division B could occur in a maple tree.
B) Division A could occur in a grasshopper and division B could occur in a maple tree.
C) Division A could occur in a grasshopper and division B could occur in an ameba.
D) Both divisions could occur in a human.

2. The diagram below represents a microscopic structure observed during the process of cell division.

[Image of cell division structure]

Letters A, B, & C, in that order, represent...

A) Spindle Fiber, Cell Plate, Chromosome
B) Centromere, Chromatids, Chromosome
C) Chromatin, Chromosome, Centriole
D) Centromere, Chromosome, Chromatids
3. The following list describes some of the events associated with normal cell division.
   - W- nuclear membrane formation around each set of newly formed chromosomes
   - X- separation of centromeres
   - Y- replication of each chromosome
   - Z- movement of single stranded chromosomes to opposite poles

   What is the normal sequence in which these events occur
   A) Y-- X-- Z-- W  B) Z-- Y-- W-- X
   C) Y-- Z-- X-- W  D) W-- X-- Y— Z

4. Upon completion of mitotic cell division, how does the genetic material of the daughter cells compare to the parent cell?
   A) Some genes are the same  B) Most genes are the same
   C) All genes are the same  D) None of the genes are the same

*These analysis questions require students to use their data (pictures) and understanding of mitosis. As an introductory lab many questions are content or verification based. Some questions, however, require students to apply their knowledge and understanding of the model and apply their knowledge at a higher-level of thinking. Analyzing data and evidence is an important science literacy skill [Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006)].
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</table>
Modeling Mitosis

Background

Cell division is an elegant process that enables organisms to grow and reproduce. Through a sequence of steps, the replicated genetic material in a parent cell is equally distributed to two daughter cells. While there are some subtle differences, mitosis is remarkably similar across organisms.

Mitosis is divided up into 5 stages with the first stage as the resting or holding stage. Before a dividing cell enters mitosis, it undergoes a period of growth called interphase. Interphase is the "holding" stage or the stage between two successive cell divisions. In this stage, the cell replicates its genetic material and organelles in preparation for division. As the cell begins to divide, it moves through distinct phases even though the process is continuous.

Materials: Cell phase diagrams , pipe cleaners , beads , string

Objectives
1. Identify the phases of mitosis based on descriptions
2. Use bead and pipe cleaners to illustrate the phases of mitosis

Procedure
Part I- Reviewing Mitosis
1) List the 5 stages of mitosis beginning with the resting stage:

1. __________________ 2. __________________ 3. __________________ 4. __________________ 5. __________________

2) Below are descriptions of each stage of mitosis. Identify which stage is being described by writing the correct stage in the blank.

<table>
<thead>
<tr>
<th>Stage Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>-centromeres divide</td>
<td>-X-shaped chromosomes separate and sister chromatids move to opposite poles</td>
</tr>
<tr>
<td>-chromosomes line up at the middle or equator</td>
<td>-centromeres attach to the spindle fibers</td>
</tr>
<tr>
<td>-resting stage- DNA appears as chromatin</td>
<td>-centrioles and other organelles replicate -chromosomes replicate to form sister chromatids</td>
</tr>
<tr>
<td>-chromatin condenses into X-shaped chromosomes</td>
<td>-chromosomes begin to migrate toward equator -centrioles separate and spindles begin to form</td>
</tr>
<tr>
<td>-chromosomes gather at opposite ends and return to chromatin</td>
<td>-two nuclear membranes form around chromatin</td>
</tr>
</tbody>
</table>
Part II: Modeling Mitosis

Now you are ready to demonstrate mitosis on your own. You will need to construct each phase of mitosis on the papers provided. The cell phases are already labeled for you. Although there are many things going on during mitosis, you will only need to show what is happening with the DNA, and centrioles. The cell you will be working with has a total of only 4 chromosomes, each represented by a different color.

How to start:
1) Arrange your cell phases in the correct order on your table.

2) Use the materials provided to model the process of mitosis. Be creative!

3) When you have completed all of the stages, call your teacher (Mr. Flores, Could you please come over and check our stages). Once I have checked your stages, I will initial your paper, so that you can clean up your pipe cleaners.

________ Teacher’s initials

This lab is another adaptation from the AP Biology lab manual. Like the previous lab, modeling is a science practice required by the AP Biology curriculum, and a major focus here. This lab builds upon the prior knowledge in the previous Picturing Mitosis and Understanding Mitosis labs [Dawson and Venville (2010), Lewis (2000), Aufschnaiter et al. (2008)]. Engaged with prior knowledge the lab is very “doable”, as Dawson and Venville (2010) emphasize as an important requirement to do science activities and tasks. This lab equips students with pipe cleaners, beads and string and challenges them to create a model of mitosis. There are very little instructions for a reason. It allows students to be creative. Allowing students to be creative promotes a more student-centered learning activity [Giles (2006), Otieno and Wilder (2010)]. This creates higher levels of engagement which as Yeung et al. (2010), Appleton and Lawrence (2011), Mayer (2007) claim can predict favorable academic and behavioral outcomes in the classroom. The process of mitosis can be illustrated in many ways, so long as students are able to explain and justify their reasoning. Therefore require students to have the teacher check their models before moving on. This is when the teacher can question and probe students reasoning and understanding of mitotic cell division.
Analysis
1. List the stage of mitosis.
   a. ___________________  d. ____________________
   b. ___________________  e. ____________________
   c. ___________________

2. Where in the cell is the hereditary material (DNA) located? ___________________

3. Describe in a complete sentence what must happen to the chromatin and organelles before mitosis begins and the cell divides.
   _______________________________________________________________________________
   _______________________________________________________________________________
   _______________________________________________________________________________

4. Using an animal cell with 3 chromosomes as an example, draw the five stages of mitosis using different colored pencils.
   _______________________________________________________________________________
   _______________________________________________________________________________
   _______________________________________________________________________________
   _______________________________________________________________________________
   _______________________________________________________________________________

5. Explain how mitosis occurs differently in a plant and animal cell.
   _______________________________________________________________________________
   _______________________________________________________________________________
   _______________________________________________________________________________

6. Create a memory aid that will help you remember the 5 phases of mitosis. (Example: planets of the solar system- My Very Educated Mother - helps you remember → Mercury, Venus, Earth Mars etc)
   _______________________________________________________________________________
   _______________________________________________________________________________
Manipulating Mitosis

Background

Cell division is tightly controlled by complexes made of several specific proteins. These complexes contain enzymes called cyclin-dependent kinases (CDKs), which turn on or off the various processes that take place in cell division. CDK partners with a family of proteins called cyclins. One such complex is mitosis-promoting factor (MPF), sometimes called maturation-promoting factor, which contains cyclin A or B and cyclin-dependent kinase (CDK). (See Figure 2a.) CDK is activated when it is bound to cyclin, interacting with various other proteins that, in this case, allow the cell to proceed from G₂ into mitosis. The levels of cyclin change during the cell cycle (Figure 2b). In most cases, cytokinesis follows mitosis.

![Diagram of cell cycle and MPF activity]

Figure 2. MPF Production During the Cell Cycle

As shown in Figure 3, different CDKs are produced during the phases. The cyclins determine which processes in cell division are turned on or off and in what order by CDK. As each cyclin is turned on or off, CDK causes the cell to move through the stages in the cell cycle.
Cyclins and CDKs do not allow the cell to progress through its cycle automatically. There are three checkpoints a cell must pass through: the $G_1$ checkpoint, $G_2$ checkpoint, and the M-spindle checkpoint (Figure 4). At each of the checkpoints, the cell checks that it has completed all of the tasks needed and is ready to proceed to the next step in its cycle. Cells pass the $G_1$ checkpoint when they are stimulated by appropriate external growth factors; for example, platelet-derived growth factor (PDGF) stimulates cells near a wound to divide so that they can repair the injury. The $G_2$ checkpoint checks for damage after DNA is replicated, and if there is damage, it prevents the cell from going into mitosis. The M-spindle (metaphase) checkpoint assures that the mitotic spindles or microtubules are properly attached to the kinetochores (anchor sites on the chromosomes). If the spindles are not anchored properly, the cell does not continue on through mitosis. The cell cycle is regulated very precisely. Mutations in cell cycle genes that interfere with proper cell cycle control are found very often in cancer cells.

**Figure 4. Diagram of the Cell Cycle Indicating the Checkpoints**
Background Cont’d: In this lab we are going to investigate how an environmental factor will affect the rate of root tip growth (mitosis) in garlic.

Rationale for Change
This lab is another adaptation from the AP Biology Lab Manual. In the original AP Lab they require students to use a protein called Lectin which is known to increase the rate of root tip growth in onion root tips. This is very dangerous as Lectin has been known to cause cancer! The original lab also involved using chi-square analysis inappropriately. Chi-Square analysis is a mathematical tool used to analyze the probability that your error is due to random chance alone. This requires “expected” values for the number of cells in each phase of mitosis, which cannot be determined by the methods suggested in the original lab. Therefore this lab has been modified to make it much safer, more engaging and use appropriate statistical analyses.

Hypothesis
What are some factors that could affect the rate of mitosis? Brainstorm a list with your teacher and classmates. Choose one factor to investigate and write your hypothesis below.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

Independent Variable/Manipulated Variable: _____________________________________________________

Rather than the potentially cancerous lectin, students typically hypothesize how miracle grow or glucose may improve root tip growth, or how salt or an acidic solution may halt root tip growth. This creates a safe, engaging, and student centered learning activity [Yeung et al. (2010), Appleton and Lawrence (2011), Mayer (2007), Giles (2006), Otieno and Wilder (2010)].

Controlled Variables/Variables Held Constant: ___________________________________________________

_____________________________________________________________________________________________
_____________________________________________________________________________________________

Materials and Supplies
Generate a list of materials and supplies that you will need to conduct your experiment.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
Data Collection Method:
There are a number of different methods you could use to measure root tip growth (mass, length, number, etc.).
Brainstorm a list of data collection methods with your teacher. Pick one and explain your method below:
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

What is particularly engaging about this lab investigation is that it is the first lab that challenges students to think about how to appropriately collect data. There are a number of different methods you use to measure root tip growth. Students must think critically about each method. Each method has pros and cons and weighing these out is an important process to develop a higher level of science literacy [Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006)].

Methods
Use this space to write down your step-by-step procedure for conducting your experiment. Use an extra sheet of paper if necessary.
Results
Use Microsoft excel to setup a table to record your data. You will use excel to illustrate how your independent variable affects, or does not affect the growth of garlic root tips. We will look at the class data to calculate standard deviations and perform t-test analysis.

One of the required science practices required by the AP College Board is the ability to calculate standard deviation and use it to draw conclusions about different sets of data. In this lab, students will calculate the standard deviation from the multiple trials from each concentration of Miracle Grow, Glucose, Salt solution, etc. Students will also use Microsoft excel to perform t-test analysis to determine if their independent variable is statistically having an effect on the growth of onion root tips. Students will use this mathematical analysis to validate their hypothesis, which as Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006) point out is an important skill for all science literate students.

Discussion
Based on your data, formulate a conclusion about how your independent variable affects the rate of mitosis in garlic root tips. Reference your data in your discussion to support your claims. Be sure to thoroughly explain the biological concepts involved. For example, be sure to explain why the rate of mitosis changed, or did not change, as a result of your independent variable. Use the following format when writing your discussion:

1. Claim about your independent variable affecting respiration
   a. Support by citing specific evidence/data from your graph or data table
      i. Provide further explanation about the biological concepts involved.

This, like many of the other labs, requires students to interpret and analyze data and evidence to validate their hypothesis [Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006)]. This is an important skill and core practice of science and science argumentation [Dawson and Venville (2010), Brown et al. (2010), McNeil (2009)].
Picturing Meiosis

Background

Sexual reproduction occurs only in eukaryotes. During the formation of gametes, the number of chromosomes is reduced by half, and returned to the full amount when the two gametes fuse during fertilization. The process that creates gametes is known as meiosis.

Haploid and diploid are terms referring to the number of sets of chromosomes in a cell. Gregor Mendel determined his peas had two sets of alleles, one from each parent. Diploid organisms are those with two (di) sets. Human beings (except for their gametes), most animals and many plants are diploid. We abbreviate diploid as 2n. Ploidy is a term referring to the number of sets of chromosomes. Haploid organisms/cells have only one set of chromosomes, abbreviated as n. Organisms with more than two sets of chromosomes are termed polyploid. Chromosomes that carry the same genes are termed homologous chromosomes. The alleles on homologous chromosomes may differ, as in the case of heterozygous individuals. Organisms (normally) receive one set of homologous chromosomes from each parent.

Meiosis is a special type of nuclear division which segregates one copy of each homologous chromosome into each new "gamete". Mitosis maintains the cell's original ploidy level (for example, one diploid 2n cell producing two diploid 2n cells; one haploid n cell producing two haploid n cells; etc.). Meiosis, on the other hand, reduces the number of sets of chromosomes by half, so that when gametic recombination (fertilization) occurs the ploidy of the parents will be reestablished.

Most cells in the human body are produced by mitosis. These are the somatic (or vegetative) line cells. Cells that become gametes are referred to as germ line cells. The vast majority of cell divisions in the human body are mitotic, with meiosis being restricted to the gonads.

Objectives

1. Arrange the phases of meiosis in the correct order based on diagrams.
2. Identify specific structures involved in meiotic cell division.
3. Identify the changes that occur during meiotic cell division: specifically the number of chromosomes and chromatids present in each phase.

Materials: meiosis pictures scissors glue

This lab is a modified version of one of the AP Biology required labs. The required lab calls for students to model meiosis. Constructing, modifying, and interpreting models is a science practice required in the AP Biology curriculum. This learning activity also allows students to construct a model of meiosis, however it is setup with pictures that scaffold the modeling process. Research by Dawson and Venville (2010) emphasized the importance of science activities and tasks being “doable”. This is an introductory learning activity that helps to improve student learning, and build confidence through repetition. This lab will help the student establish and build upon prior knowledge [Dawson and Venville (2010), Lewis (2000), Aufschnaiter et al. (2008)].
**Procedure:**

**Part I**

1) Look at the cards on page 5 showing the different stages of meiosis.

2) Cut out the pictures and arrange them in what you think is the correct order for meiosis.

3) Call your teacher over, “Mr. Flores, can you please come and check our pictures?”

4) Once I have OK’d your sequence, paste them to your answer sheet, page 4.

5) Use the following words to name each of the pictures:
   - Parent Cell, Interphase, Prophase I, Metaphase I, Anaphase I, Telophase I,
   - Prophase II, Metaphase II, Anaphase II, Telophase II,

**Analysis**

Use your meiosis picture sequence to answer the following questions.

1) The cells in the pictures are circular. Do you think these are plant or animal cells? __________

2) What is the diploid number for this species? ______

3) What is the haploid (monoploid) number for this species? ______

4) How many chromosomes are in a cell at the start of meiosis? ______

5) How many chromatids are in the cell at prophase I? ______

6) What pairs up during prophase I which allows for crossing over? ______ ______

7) Have homologous chromosomes separated at anaphase I? ______

8) Have sister chromatids separated at anaphase I? ______

9) Are the cells haploid or diploid after telophase I? ______

10) How many chromosomes are present in each cell in prophase II? ______

11) How many chromatids are present in each cell in prophase II? ______

12) How is anaphase II different from anaphase I? (Use sister chromatids and homologous chromosomes in your response)

__________________________________________________________________________________________
__________________________________________________________________________________________
__________________________________________________________________________________________

13) Compare the number of chromosomes in each cell at the end of telophase II with the number of chromosomes present in the parent cell?
14) Are the cells in the 4 daughter cells haploid or diploid? __________________

15) How many times have the chromosomes replicated during meiosis? _________

16) Why do you think meiosis is sometimes called reduction division? Justify your answer by referencing the pictures.

__________________________________________________________________________________________
__________________________________________________________________________________________
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17) What will the resulting 4 daughter cells eventually become? ______________ or ____________

18) Why is this reduction division so important (hint: think about what meiosis produces and what you do with the 2 products of meiosis)?

__________________________________________________________________________________________
__________________________________________________________________________________________
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These analysis questions require students to use their data (pictures) and understanding of meiosis. As an introductory lab many questions are content or verification based. Some questions, however, require students to apply their knowledge and understanding of the model and apply their knowledge at a higher-level of thinking. Analyzing data and evidence is an important science literacy skill [Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006)].
<table>
<thead>
<tr>
<th>Telophase I &amp; Cytokinesis</th>
<th>Telophase I &amp; Cytokinesis</th>
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<tbody>
<tr>
<td>Anaphase I</td>
<td>Anaphase II</td>
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<tr>
<td>Metaphase I</td>
<td>Metaphase II</td>
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<tr>
<td>Prophase I</td>
<td>Prophase II</td>
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</tbody>
</table>
Modeling Meiosis

**Background:** Meiosis is the process which creates gametes with half the number of chromosomes as the parent cells. The process of fertilization restores the regular number of chromosomes to the zygote. In this lab you will demonstrate how the chromosomes in parent cell is multiplied one time, and then divided two times to create daughter cells with half the amount of chromosomes.

**Objective:**
1) identify the phases of meiosis
2) construct models representing each phase of meiosis

**Materials:** Meiosis Modeling Kit Stages of Meiosis Sheets

**Procedure:**

1. Gather around your teacher’s desk to watch a brief demonstration. Be sure you understand which materials represent the following:
   a. Centrioles
   b. Centromeres
   c. Chromosomes
   d. Homologous Chromosomes
2. Arrange the phases of meiosis in the correct order. You can do this on the floor or on your lab table.
3. Use the materials provided to model the process of meiosis. Be creative! As you complete each phase be sure to:
   a. Draw, using colored pencils, how your cells look in the results sections.
   b. Get your teachers initials at the important checkpoints before moving on.

*This lab is another adaptation from the AP Biology lab manual. Like the previous lab, modeling is a science practice required by the AP Biology curriculum, and a major focus here. This lab builds upon the prior knowledge in the previous Picturing Meiosis lab [Dawson and Venville (2010), Lewis (2000), Aufschnaiter et al. (2008)]. Engaged with the prior knowledge the lab is very “doable”, as Dawson and Venville (2010) emphasize as an important requirement to do science activities and tasks. This lab equips students with different colored and sized magnetic pop-off beads (chromosomes), string and empty cell cycle phase diagrams to challenge them to create a model of meiosis. There are very little instructions for a reason. It allows students to be creative. Allowing students to be creative promotes a more student-centered learning activity [Giles (2006), Otieno and Wilder (2010)]. This creates higher levels of engagement which as Yeung et al. (2010), Appleton and Lawrence (2011), Mayer (2007) claim can predict favorable academic and behavioral outcomes in the classroom. The process of meiosis can be illustrated in many ways (crossing over, independent assortment, etc), so long as students are able to explain and justify their reasoning. This is why it is necessary for the teacher to check student models at critical points in meiotic cell division before allowing students to move on. This is also an opportunity to question and probe students reasoning and understanding of meiotic cell division.*
Results
Meiosis One

Teacher’s Initials

Meiosis Two

Teacher’s Initials

Teacher’s Initials
Analysis

1) At what stage of meiosis is the number of chromosomes halved? ___________________________

2) Describe what happens to homologous chromosomes during meiosis? ___________________________________
__________________________________________________________________________________________________
____________________________________________________________________________________________

3) Look at your drawing for metaphase I. There is another way your chromosomes could have aligned themselves. Draw this in the cell below labeled metaphase I. Complete the following drawings using the appropriate colors. NOTE: You DO NOT need to show crossing-over again.
4) Compare the 4 daughter cells from your models to the 4 daughter cells above. Are they the same? Explain.
__________________________________________________________________________________________________
__________________________________________________________________________________________________
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5) When the chromosome number is halved during meiosis, why are some characteristics not lost?
__________________________________________________________________________________________________
__________________________________________________________________________________________________
__________________________________________________________________________________________________
__________________________________________________________________________________________________

6) Describe how the final daughter cells would be affected if homologous chromosomes failed to separate at anaphase I.
__________________________________________________________________________________________________
__________________________________________________________________________________________________
__________________________________________________________________________________________________
__________________________________________________________________________________________________

7) Complete the following graph. On the x-axis write in the phases of meiosis in order. When the line for the amount of genetic material per cell changes in height, indicate with an arrow the event that took place (replication, separation of chromosome, etc.). With a second color sketch the diversity of the genetic material present within a cell. When the height of the diversity line changes, indicate with an arrow, what event took place (crossing over, independent assortment, etc). Include a key.

<table>
<thead>
<tr>
<th>Relative Amount of Genetic Material per Cell</th>
<th>-OR-</th>
<th>Diversity of Genetic Material per Cell</th>
</tr>
</thead>
</table>

Time
This analysis question requires students to really apply their knowledge and understanding of meiosis. Students understand the process of meiosis in a time-line of events, but can they take their knowledge of the timeline and represent it in another format? This graph is a challenge to do just that. A common struggle for students is to differentiate between the separation of homologous chromosomes and sister chromatids. Analyzing the data and evidence from their model drawings will help students gain a deeper understanding of meiotic cell division [Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006), Kur and Heintzmann (2008)].
Investigating Natural Selection: Feeding Appendages

Background:

To learn in a concrete way how natural selection operates, we will create a simulation of evolution by natural selection. In this simulation, members of the class will be predators that vary in the shape of their mouthparts. The feeding appendages used for catching prey come in four varieties: spoons, forks, chopsticks, and straws.

In this population, individuals who catch more than the median number of prey survive and have enough energy to produce one offspring. Individuals who catch fewer than the average number of prey will die of starvation before reproducing. In order to study evolution by natural selection, we will track the frequency of these four variants over several generations. We will also follow the median prey captured to determine who will survive and who will perish.

Objective

- To understand the process of natural selection.
- To understand how selective pressures such as natural variation in feeding appendages shape and size or seed shape and size affect population size and allele frequencies over time.

Hypothesis

Hypothesize which feeding appendage is going to be most successful at feeding on the kidney beans.

Having students generate a rich hypothesis immediately places the student in the driver seat. They begin to think critically, reason scientifically and immediately become engaged in the lesson. Students study the shape and size of the kidney beans different feeding appendages. They start to become in control of their own learning. This helps create an engaging atmosphere that promotes active learning in the classroom [Yeung et al. (2010), Otieno and Wilder (2010), Mayer (2007)].

Procedure:

1) Start with a population that is 25% of each of the four variations. Record this information in Data Table 1 for Generation 0.

2) Food will be thrown on the ground and will be available for the individuals.

3) When your teacher says "Feed," place as many pieces of food in your cup as possible. This must be done one at a time. You are not to touch any other individuals. The search is over when the teacher called "Time."

4) Determine the median number of prey capture by forming a line beginning with the individuals with the least amount of food to the most amount of food.
5) All individuals below the median die and must turn in the utensil. All individuals above the median should select their same utensil and give it to an empty handed individual. This simulates reproduction of the successful organisms and death of the unsuccessful organisms.

6) Record how many of each variant is in this new population, and record it in the data table for Generation 1.

7) Repeat steps 2-6 for 6 generations.

8) Construct a graph showing the number of individuals of each type in each generation using a different color line for each variant. Draw a legend to show which color represents which variant.

Understanding natural selection is pivotal to understanding the process of evolution. And understanding evolution is pivotal to understanding pretty much EVERYTHING in biology. A famous Russian evolutionary biologist, Theodosius Dobzhansky, once wrote “Nothing in Biology makes sense except in light of evolution.” The mechanism, or driving force of evolution is Natural Selection. Students, however, often struggle at really grasping how a population can change over time. It involves a lot of mathematical reasoning of different survival and reproductive rates proceeding over several generations. This lab will demonstrate and help students understand exactly how natural selection works and how the differential survival and reproductive rates can cause a species or population to change over time.

The simulation begins with an equal variance of feeding appendages. Over successive generations organisms born with unfavorable traits die out and organisms born with favorable traits become more common in the gene pool. Students literally see and experience the class changing over time. Having the students participating in this hands-on “struggle for survival and reproduction” activity creates an engaging and student-centered learning atmosphere [Yeung et al. (2010), Appleton and Lawrence (2011), Mayer (2007), Giles (2006), Otieno and Wilder (2010)]. They observe, experience and record the changes in feeding appendages in their results section and graph it over time. This highly engaging learning activity, as Yeung et al. (2010), Appleton and Lawrence (2011), Mayer (2007), and Kur and Heintzmann (2008) claim, can predict favorable academic and behavioral outcomes in the class where students become masters of the content.

### Results

<table>
<thead>
<tr>
<th>Generation</th>
<th>Spoons</th>
<th>Forks</th>
<th>Straws</th>
<th>Chopsticks</th>
<th>Total</th>
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<td>0</td>
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<td>Initial Variant Frequency</td>
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<table>
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Analysis

1. For natural selection to occur there must be variation, competition, and passing on of traits. Describe how each criterion was met during the lab activity.

Variation- ________________________________________________________________

________________________________________________________________________

Competition- ____________________________________________________________

________________________________________________________________________

Passing on of traits- ______________________________________________________

________________________________________________________________________

2. Did individuals change over time, or did the frequencies of the variants change over time?

________________________________________________________________________

3. Why did these changes occur? ____________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
4. Has evolution occurred in the population? Justify your answer using evidence from your graph or table.

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__________________________________________________________________________________________________
__________________________________________________________________________________________________
__________________________________________________________________________________________________

5. Predict what would happen if the weather changed which caused the food source changed to seeds that had the shape and size of sesame seeds?

__________________________________________________________________________________________________
__________________________________________________________________________________________________
__________________________________________________________________________________________________
__________________________________________________________________________________________________

6. Predict what would happen if a genetic mutation caused the chopstick feeding appendage to attach and anchor at the base making the chopsticks function like tweezers.

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These analysis questions require students to use their data and graph to develop a deeper understanding of evolution. As an introductory lab some questions are content or verification based. Many questions, however, require students to apply their knowledge and understanding of the model, manipulate variables, and apply their knowledge at a higher-level of thinking. Analyzing data and evidence is an important science literacy skill [Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006)].
Variation Within a Species

Background

Evolution is an integral biological process that provides both the unity and diversity of all life on Earth. A famous Russian evolutionary biologist, Theodosius Dobzhansky, once wrote “Nothing in Biology makes sense except in light of evolution.” The mechanism, or driving force of evolution is Natural Selection. One of the principles of natural selection is variation. Without variation, evolution by natural selection is not possible. The more variation that exists within a population the greater the odds are that at least some organisms will be able to survive a sudden environmental stress and hence, pass on their genes.

In this lab investigation we will ask questions about nature, specifically about what variation exists within a population. We will collect and measure data to try and come up with a possible biological explanation for the data we collect.

Objectives:

To collect and measure data quantitatively.
To observe variation within a species.
Draw conclusions based on the quantitative data collected about the variation.

This is an engaging student-centered lab in that it is very open-ended and has endless possibilities. To understand evolution by means of natural selection, students need to understand that variation always exists within a population. For students it is easy to grasp and understand this concept with humans, but students struggle at grasping this concept with other plants and animals. They see a flock of geese or leaves hanging from a tree and think that they are all the same. In actuality, the beaks of those geese are all different. Some are longer, thinner or wider than the other beaks in its population. Likewise, all of the leaves hanging from the tree all have different surface areas, or leaf stem lengths, masses or what have you. In this lab, students ask similar questions about nature and collect and analyze data to draw conclusions. This activity is very student-centered [Giles (2006), Otieno and Wilder (2010)], and inquiry-based in design. This type of engaging inquiry-based mode of learning encourages a more cohesive learning experience where students improve attitudes towards science and become masters of the content [Kur and Heintzmann (2008), Wolf and Fraser (2007), and Lord and Orkwiszewski (2006)].

Procedure

1. With your teacher and fellow classmates, brainstorm a list of characteristics that could vary within a population. Try to focus your list to characteristics that are readily available on the school campus. Pick one characteristic and write it below.

   Biotic Characteristic: ______________________

   Possibilities include leaf stem length, leaf mass, acorn mass, width or diameter, etc. Plants are very abundant on school campuses so most selections will have to be plant-based.

2. Go outside and gather as many specimens as possible. Bring them back into the lab to measure.
3. Put your head together with your lab partners to figure out the best way to measure your data quantitatively.
   a. For example, if you were going to measure the mass of acorns on the ground, using a triple beam balance would not be best because it would be timely and acorns are very light. A triple beam balance
may not be sensitive enough measure the difference in masses between acorns. An electric scale that quickly measure to the thousandths of a gram would be more appropriate.

_Having students think about their data collection method promotes higher level and critical thinking skills. Rather than tell the students how to collect the data, students must work together to come up with an appropriate method of data collection. This cooperative, inquiry based method to learning places the student at the focus of the learning process. [Kur and Heintzmann (2008), Wolf and Fraser (2007), and Lord and Orkwiszewski (2006)]. Understanding when and why certain data collection methods are more appropriate that others is a science practice required by the AP College Board. This skill set is necessary to build a scientifically literate population within the classroom [Dillon (2009), Their (2010), CCSS Initiative (2011)]._

4. Measure your specimens and record them all on a separate piece of paper.
5. Once you have recorded all of the data, create about 6-8 intervals of equal value that will quantify all of your measurements. This will be your data table. Be sure your data table is setup so that you can include data from the rest of the class.
   a. **Ex.) Length of a Leaf Stalk:**

<table>
<thead>
<tr>
<th>16-18.9 mm</th>
<th>19mm-21.9 mm</th>
<th>22mm-24.9 mm</th>
<th>25mm-27.9 mm</th>
<th>28mm-30.9 mm</th>
<th>31mm-33.9 mm</th>
<th>34mm-36.9 mm</th>
<th>37mm-39.9 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Share your data with the rest of the class. Be sure you have recorded the data from the entire class.
7. Create a bar graph that represents the distribution of your data.

**Results**
Analysis
1. What measurement range has the greatest frequency? _____________________
2. What measurement range has the lowest frequency? ______________________
3. Describe the shape of the curve determined by the data. _____________________
4. What is the benefit of variation within a species? ____________________________________________________________________________
   ____________________________________________________________________________
   ____________________________________________________________________________
   ____________________________________________________________________________
   ____________________________________________________________________________
   ____________________________________________________________________________
   ____________________________________________________________________________

5. Provide a biological explanation for the variation that exists amongst your specimens.
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6. Now that you have investigated this, what is another question you could ask and measure?
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These analysis questions are design to have the students analyze and interpret their data and evidence [Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006)]. Students come to the conclusion that nature, like the universe, is random. They will see in their graph that a bell-curve exists. This is mathematical evidence that variation does in fact exist in a population. The writing frame set forth in the analysis section is designed to encourage students to make a decision about variation and articulate reason, with evidence for their decision. This, as Dawson and Venville (2010) point out, is an important and core practice of science. Understanding the random nature of life on Earth is also an important concept that will be further investigated later on in the Evolution unit when we learn about different types of selection (directional, disruptive, stabilizing, etc.). Building upon prior knowledge is essential to learning science [Dawson and Venville (2010), Lewis (2000), Aufschnaiter et al. (2008)].
Understanding Evolutionary Relationships: Tree-Thinking

Background

The following protocol will take you through the steps required to build a phylogenetic tree with molecular data using SeaView, a freely available computer program. Molecular data for many known organisms is available from GenBank, a database hosted by the National Center for Biotechnology Information (NCBI). NCBI provides a helpful resource for learning how to understand and interpret phylogenetic trees, which can be found at http://www.ncbi.nlm.nih.gov/About/primer/phylo.html. These procedures can be adapted for students to use in formulating and testing evolutionary hypotheses.

This lab is a significant improvement from one of the required AP Biology Labs. In the original lab it involves students using Genbank from NCBI.gov to investigate the evolutionary relationships between organisms. However, the program and method used in the AP Lab manual is not very good. It depicts the relationships in a jumbled and confusing manner. It takes a long time to format the evidence and can be very confusing to students. This lab uses a different program, Seaview, to analyze the same genetic evidence to draw evolutionary relationships between closely related organisms. Seaview is free, available on the internet, and does an excellent job at analyzing genetic sequences and clearly displaying the similarities and differences in a phylogenetic tree.

In the procedure, students will use published genetic information to investigate the evolutionary relationship between closely related organisms. They can choose almost any organisms they want, so long as they are fairly closely related. So for example, if a student is really interested about Horse or Whale evolution they can dive deep into the Genbank library and seek out answers to their evolutionary past. Although the methods are very much teacher-driven, the nature of this lab is student-centered because they are free to investigate any group of animals they like. Many students are fascinated, and often surprised by the evolutionary history of organisms. For example, students are typically surprised to learn that Whales have ancestors that once walked on land. This type of learning is both engaging and inquiry-based [Kur and Heintzmann (2008), Wolf and Fraser (2007), and Lord and Orkwszewski (2006)]. It promotes student-centered learning that engages the learner [Yeung et al. (2010), Appleton and Lawrence (2011), Mayer (2007), Giles (2006), Otieno and Wilder (2010)].

Procedure

Find a Nucleotide Sequence

2. In the “Search” window, select “Gene” from the pull-down menu. Type in the organism you’re looking for and the gene if you know it. In this case, start with COX1. Push Go.
The cytochrome oxidase 1 (COX1) gene is a mitochondrial gene involved in respiration. It is a commonly sequenced gene and there are COX1 sequences available for a wide variety of organisms. You can use other genes, but you must choose the same gene for all the organisms you are comparing.

**Tip:** For more unusual species, try a search using the genus name of the species you are looking for instead of the common name to enhance the specificity of your search.

3. In the search results, click on the “COX1” link for the species you want to investigate.

5. The sequence viewer will appear, showing many lines of DNA sequence (combinations of A, T, G, and C). Highlight all of this text, including the first line (this is the sequence header). Copy the text to your clipboard.

```
>gi|17981852:5905-7446 Homo sapiens mitochondrion, complete genome
ATGTTAGCCCCACGTTGACTTCTCTACCCAAACACAAAGACATGGAAACACTATCCCTATTTATGCGCT
CACGGACACAGTGACATGCTCTACCCCTCTCCTCATCTACTCTGCTGGAACATCCGTA
AGTTAGCCCCACGTTGACTTCTCTACCCAAACACAAAGACATGGAAACACTATCCCTATTTATGCGCT
CACGGACACAGTGACATGCTCTACCCCTCTCCTCATCTACTCTGCTGGAACATCCGTA

```

6. Open your text-editing program (Notepad (PC) or TextEdit (Mac) – please do not use Microsoft Word). Open a new document. Paste the DNA sequence text from your clipboard.

7. Save the file as sequences.txt

**Tip:** Mac users must convert the file to plain text before saving. To do this, click on the Format menu at the top of your screen and then choose the option “Make plain text”. If the file extension is .rtf, the file will not be read.

8. Keep the file open. You’ll need it in the next step.

**Add more sequences**

COX1 is a useful gene for comparing organisms within relatively closely related groups and is especially good for studying the relationships between animals. The mutation rate in this gene is too high for accurate comparison between distantly related organisms, such as a paramecium and a human. For best results, choose the majority of your organisms from WITHIN a group that you are interested in, such as Carnivora (carnivores) or Aves (birds). In addition, you must choose one organism that is OUTSIDE this group, which will become your outgroup.

10. Search for additional organisms that you want to add to your tree. Follow steps 2-5 again.

11. Return to your text-editing program. Instead of creating a new file, copy and paste the new sequences into your FASTA file below the first one. Make sure you include the sequence header beginning with “>” at the start of each sequence. Save your file as you go.

12. Repeat Steps 2-11 until you have a minimum of 8-10 sequences in your FASTA file.

**Edit the FASTA file**

13. Let’s look at the sequence header at the top of each DNA sequence. The species title that will show up on your tree will be the first line of each set of sequence data following the “>” symbol. This header can be edited for clarity, but you **MUST** preserve the “>” symbol. You can use the scientific name or the common name to identify your sequence.

For example, the human sequence begins like this:

```
>gi|251831106:5904-7445 Homo sapiens mitochondrion, complete genome
```

This can be edited to look like this:

```
>Human
```

Or this:

```
>Homo_sapiens
```

*Tip: Be sure to add an underscore “_” instead of a space between words. That way all words you include will show up as labels on your tree.*

14. Make sure you have a return after your header and after the end of the sequence. Your list of sequences should appear as follows:

```
>Human
ATGTTCGCCGAC...
```

```
>Pan_paniscus
ATGTTCACCGAC...
```

*Tip: Each sequence should be approximately 1500 bp, which should appear about the length of a “paragraph” in your file. If any seem to be much longer, see Step 18.*

**Align your sequences**

15. Open the program SeaView. To access the program go to: “Computer; W-drive; Science; Flores; Evolution; Seaview”

16. In the File menu, choose Open.
17. Select your file. Your sequences should show up in the SeaView window. Check to see that they are all present, labeled correctly, and that the first few bases in the SeaView window correspond to the first few bases of each sequence in your text file.

*Tip: If your file will not load into SeaView, or does not load correctly, check for the following common problems:*

a. Your file is in .doc or .rtf format. Look at the extension after the file name. It must end in .fasta or .txt. Open it in Notepad or Textedit and save as a plain text file.
b. You have accidentally deleted the “>” character at the beginning of one or more sequence headers. Simply add “>” back to the front of each sequence header.
c. You are missing one or more carriage returns at the end of each header and sequence. To fix this, place your cursor at the end of each sequence and header and consciously add a return even if one appears to be there already.

18. Scan your sequences. They should all be roughly 1500 bp in length. If any of them are much longer than the others (eg. 16,000 bp), you may have accidentally downloaded the entire mitochondrial genome for that organism. Go back to Step 4 and make sure that you have extracted the COX1 portion only.

19. Under the Align menu choose **Align All**.

20. A new window will pop up that shows the alignment algorithm running in real time. When it is complete, click **OK**.

21. Scan the sequences again. Do you notice any changes? You may see that gaps have been inserted into some sequences. Think about why the program might be doing this. It’s also possible you won’t see any changes at all, particularly if your chosen organisms are very closely related.

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**Build the tree**

22. Go to the Trees menu towards the right of the menu bar. Click “Trees” then “Parsimony”. This will build a tree using the principle of Maximum Parsimony.

23. Click “OK” to agree to the default settings for the various options available.
24. A new window will appear with your tree. The relationships it shows may appear strange or
counterintuitive to you at first. It is **VERY** important to set your outgroup (see next step) before
analyzing your tree.

**Manipulating the tree**

25. Click **Re-root**. Black boxes will appear on your tree. Click the black box next to the organism that will
serve as the outgroup. This organism should be the one you selected in Step 13 as the organism outside
your main group of interest, making it the **most different** from all the other organisms on your tree.

26. Use the **Swap** command to swap the branches around the nodes by clicking the black box representing
the node that you would like to swap. You can also zoom in on a subsection of your tree by clicking **Subtree**
and then the black box representing the node you want to zoom in on. Click **Full** to eliminate
buttons on the tree or to return to the main tree.

**Print your tree**

27. Take a screenshot of your tree. There are different methods to do this, depending on your computer:

**Using Windows:**

a. Press the **Print Screen** button on your keyboard.
b. Open **Microsoft Word** or **Microsoft Paint**.
c. In the Edit menu, choose **Paste**. Your image will appear in the document.
d. Crop and Format the picture to be “In Front of Text”
e. Label the tree “Maximum Parsimony”
f. Save the document to share with others.

**Using Mac:**

a. Press **Command-Shift-3** using your keyboard (do not use the 3 on the number pad of a full
size keyboard).
b. A file will appear on your desktop called **Picture 1**.
c. This image is ready to insert into **Microsoft Word**.

**Try another tree-building method**

28. Go to the Trees menu towards the right of the menu bar. Click “Trees” then “PhyML”. This will build a
tree using the principle of **Maximum Likelihood**.
29. Click “Run” to agree to the default settings for the various options available.

30. A new window will pop up that shows the tree-building algorithm running in real time. When it is complete, click **OK**:

31. Your new Maximum Likelihood tree will appear. Repeat step 25 to set the outgroup for this tree before you analyze and compare your trees. You can also use the **Swap** command again to re-arrange the branches.

32. Click **Full** to return to the main tree view, then click **Br Lengths** near the top of your tree window. Numbers will appear along your branches. These numbers depict the amount of divergence relative to the changes in base sequences. Put your two trees side by side so that you can compare and contrast their appearance and the relationships they show. Label this tree “Maximum Likelihood”.

![ Phylogenetic Trees](image)

Answer the following questions in a section labeled “Discussion” on the word doc containing your 2 phylogenetic trees.

1. Describe some of the evolutionary relationships depicted by your tree.

2. Why did you choose this group of organisms to build your tree. Your answer MUST refer to cox1. *Hint: read back through the lab for clues about the gene cox1.*

3. What organism did you pick as your outgroup. Why? What is the function of the outgroup.

4. Which of your 2 trees was Ultrametric? Phylogram? Explain your reasoning.

5. How awesome was this lab?!?!
These analysis questions are designed to have the students analyze and interpret their data and evidence [Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006)]. Students analyze an abundant source of data to conclude that all life forms are related yet diverse and unique in their own right. The writing frame set forth in the analysis section is designed to encourage students to make a decision about the evolutionary relationships between their chosen animals and articulate reason, with evidence for their decision. This, as Dawson and Venville (2010) point out, is an important and core practice of science.
Investigating Net Primary Productivity

Background

Almost all life on this planet is powered, either directly or indirectly, by sunlight. Energy captured from sunlight drives the production of energy-rich organic compounds during the process of photosynthesis. These organic compounds create biomass. The net amount of energy captured and stored by the producers in a system is the system’s net productivity (NPP). Gross productivity (GPP) is a measure of the total energy captured. In terrestrial systems, plants play the role of producers. Plants allocate that biomass (energy) to power their life processes or to store energy. Different plants have different strategies of energy allocation that reflect their role in various ecosystems. For example, annual weedy plants allocate a larger percentage of their biomass production to reproductive processes and seeds than do slower growing perennials. As plants, the producers are consumed or decomposed, and their stored chemical energy powers additional individuals, the consumers, or trophic levels of the biotic community. Biotic systems run on energy much as economic systems run on money. Energy is generally in limited supply in most communities. Energy dynamics in a biotic community is fundamental to understanding ecological interactions.

To model ecosystem energy dynamics, you will estimate the net primary productivity (NPP) of bean plants (the producers) growing under lights and the flow of energy from plants to cabbage white butterfly larvae (the consumers) as the larvae eat cabbage-family plants in a later lab.

Objectives

• To design and conduct an experiment to investigate a question about energy capture and flow in an ecosystem
• To explain community/ecosystem energy dynamics, including energy flow, NPP
• To predict interspecific ecological interactions and their effects
• To use mathematical analyses in energy accounting and community modeling
• To make the explicit connection between biological content and the investigative experience

Safety

• Disease outbreaks are common in cultured populations of organisms. Although the diseases associated with the organisms in this investigation are not dangerous to humans, it is important to maintain cleanliness in the laboratory and of your experimental equipment to minimize possible impacts on the study caused by disease.
• The plants and soil can simply be discarded when the experiment is done.
• Long-term culturing for plants or butterflies requires cleanliness. Be sure to clean all culturing chambers and wipe them down with dilute Clorox (and dry completely) before starting another generation of plants or butterflies. Use new materials if you have any doubts.

This lab is another adaptation from a required lab in the AP Biology Lab Manual. The original version is great in theory, but flawed in methodology. The original assumes that students will be able to figure out too much on their own. Science activities must be "doable" [Dawson and Venville (2010)]. When the science activity is too difficult, which can happen often in inquiry-based activities, students can become stressed and shut down. Therefore, this lab is modified and scaffolded so that students can learn the basic skills necessary to measure changes in biomass, and convert that to energy. This will help students be successful and build a solid foundation of knowledge, skills, and content.

Procedure

Primary productivity is a rate — energy captured by photosynthetic organisms in a given area per unit of time. Based on the second law of thermodynamics, when energy is converted from one form to another, some energy will be lost as heat. When light energy is converted to chemical energy in photosynthesis or transferred from one organism (a plant or producer) to its consumer (e.g., an herbivorous insect), some energy will be lost as heat during each transfer.

In terrestrial ecosystems, productivity (or energy capture) is generally estimated by the change in biomass of plants produced over a specific time period. Measuring biomass or changes in biomass is relatively straightforward: simply mass the organism(s) on an appropriate scale and record the mass over various time intervals. The complicating factor is that a large percentage of the mass of a living organism is water — not the energy-rich organic compounds of biomass. Therefore, to determine the biomass at a particular point in time accurately, you must dry the organism. Obviously, this creates a problem if you wish to take multiple measurements on the same living organism. Another issue is that different organic compounds store different amounts of energy; in proteins and carbohydrates it is about 4 kcal/g dry weight and in fats it is 9 kcal/g of dry weight. As you plan your own investigation, take into consideration all the above information.

PLANTING – Day 1

1. Begin this investigation by choosing a type of plant or producer. As a class we will grow 2 different types of plants. Identify your plant below. This will be the plant type that you measure for the rest of the lab.

   Choice Plant (Producer) ____________________________

2. Fill each potting chamber with potting mix (soil). Scrap off any excess potting soil at the top. Tap the chamber a couple of times to settle the soil.
3. Dampen the soil with water. NOTE - the potting mix should be lightly moistened, but it should not be wet enough for water to be squeezed out.
4. Drop seeds on top of the moistened soil.
5. Cover the seeds with the potting mix and water lightly to wet the surface.
6. Cover the chamber with the clear plastic dome. Place the chamber by the window.
7. Periodically check on your seeds to make sure that the soil hasn’t dried out.

Having students select and plant a plant of their own choosing is an engaging hands on way to begin the lab with a student-centered approach. By having students raise and care for their own plants, students take ownership of the learning process. This type of student-centered inquiry based instructional strategy promotes favorable academic and behavioral outcomes in the classroom [Yeung et al. (2010), Appleton and Lawrence (2011), Mayer (2007), Giles (2006),]
MEASURING NPP – Day 14

8. In the results section, construct a diagram to model energy capture and flow through a plant. It should look similar to the following:

![Diagram of Energy Flow in a Plant]

Think about what the arrows represent. How could you measure, or estimate, each arrow?

9. Also in the results section, construct a table that includes the following:
   a. Time, Wet Mass/10 plants, Dry Mass/10 plants, % Biomass/10 plants, Energy/10 plants, NPP per day per plant

10. Before moving on, check with your teacher to make sure your energy flow diagram and table are setup properly. Teacher’s Initials: ________________

   Requiring teacher initials here is a great opportunity to ensure that the lab is in fact “doable” as Dawson and Venville (2010) describe as so important to learning science.

11. Remove about 10 plants from the chamber. Be sure to not destroy and get all of the roots. Remove as much soil from the roots as possible. Again, be careful not to destroy the roots!
12. Mass the plants on a scale. Record the wet mass in your table.
13. Label the plants and place it in the incubator to dry out.
14. After 48 hours, remove the plants and mass them again. Record the dry mass in your table. Calculate the % biomass.
15. Recall that stored energy in proteins and carbohydrates is about 4 kcal/g dry weight and in fats it is 9 kcal/g of dry weight (see background above). Bean plants consist primarily of carbs and proteins so the average stored energy of bean plant is 4.35 kcal/g. Calculate the Energy/10 plants and NPP/plant/day.

MEASURING NPP – Day 21 or 28

16. Repeat steps 11-15 with all of the remaining plants.
17. Use your data table to fill in number values for your energy flow diagram.

Results

You should have the following in your results section:
- Energy Flow diagram with measured and estimated number values for each arrow.
- Data Tables for your measurements at day 14 and 21/28.

Analysis

1. How much of your plant is water? Justify your answer using data from your table.

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2. Compare the NPP from days 1-14 and days 14-21/28. Were they the same? Provide a biological explanation for why the NPP changed, or stayed the same.

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3. Identify 3 factors that could NPP of bean plants. For each factor, explain how it could affect NPP.

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4. What other methods could be used to measure GPP and NPP? Explain your reasoning. *Hint – think about the gases involved in the processes of cellular respiration and photosynthesis*
5. Make a poster that illustrates NPP. Include your measured and estimated data in your poster. Present it to your classmates, then tape it up outside in the hallway.

This lab requires students to record data and conduct mathematical analyses to convert grams of biomass to kcal of energy. Using math to convert and analyze data is another skill students must learn to promote a population of critical thinkers and consumers of science [Dillon (2009), Their (2010), CCSS Initiative (2011)]. Students also use their mathematical conversions to create a model of energy flow in an ecosystem. Constructing, interpreting and manipulating models is a science practice required by the College Board. When students analyze data, evidence and models to validate hypothesis and form conclusions they are becoming true consumers of science [Dillon (2009), Thier (2010), CCSS Initiative (2011), Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006)].
Investigating Energy Flow Between Producers and Cabbage Butterfly Larvae

Background

In a previous lab we measured the NPP of growing bean plants over two time intervals. Recall that NPP is the net amount of energy captured and stored by the producers in a system. Gross productivity (GPP) is a measure of the total energy captured. In terrestrial systems, plants play the role of producers. Plants allocate that biomass (energy) to power their life processes or to store energy. As plants, the producers are consumed or decomposed, and their stored chemical energy powers additional individuals, the consumers, or trophic levels of the biotic community. Energy dynamics in a biotic community is fundamental to understanding ecological interactions.

Cabbage white butterfly larvae eat plants from the cabbage family. As with the bean plants from the earlier lab, accounting for energy flow into and out of these butterflies can be inferred from biomass gained and lost. In this lab investigation, we are going to model energy dynamics by calculating the energy flow between Brussels Sprouts (producers) and Cabbage Butterfly Larvae (consumers).

Objectives
- To design and conduct an experiment to investigate a question about energy capture and flow in an ecosystem
- To explain community/ecosystem energy dynamics, including energy flow, NPP, and primary and secondary producers/consumers
- To predict interspecific ecological interactions and their effects
- To use mathematical analyses in energy accounting and community modeling
- To make the explicit connection between biological content and the investigative experience

This lab is another adaptation from a required lab in the AP Biology Lab Manual. It builds upon and is an extension of the previous lab. Like the previous lab, the original assumes that students will be able to figure out too much on their own. As mentioned in the previous lab science activities must be “doable” [Dawson and Venville (2010)]. When the science activity is too difficult, which can happen often in inquiry-based activities, students can become stressed and shut down.
Therefore, this lab has also been modified and scaffolded so that students can learn the basic skills necessary to measure changes in biomass, and convert that to energy. This will help students be successful and build a solid foundation of knowledge, skills, and content.

Safety
- Cabbage white butterflies (*Pieris rapae*) are listed as a pest species by the USDA. Therefore, no butterflies or larvae raised in the laboratory should be released to the wild.
- Euthanize the butterflies or larvae by freezing them when your investigation is complete. The plants and soil can simply be discarded.
- Disease outbreaks are common in cultured populations of organisms. Although the diseases associated with the organisms in this investigation are not dangerous to humans, it is important to maintain cleanliness in the laboratory and of your experimental equipment to minimize possible impacts on the study caused by disease.
- Long-term culturing for plants or butterflies requires cleanliness. Be sure to clean all culturing chambers and wipe them down with dilute Clorox (and dry completely) before starting another generation of plants or butterflies. Use new materials if you have any doubts.

Procedure

Day 1

1. In the results section, construct a diagram to model energy capture and flow through Butterfly Larvae. It should look similar to the following:

   ![Energy in a Butterfly Larvae](image)

   **Figure 3. Energy Flow from Plants to Cabbage Butterfly Larvae**

   Think about what the arrows represent. How could you measure, or estimate, each arrow?

2. As butterfly larvae grow toward maturity, they pass through different developmental stages called instars. You will use larvae that are already well along their developmental path through the larval stages (4th or 5th instar).

   ![Butterfly Life Cycle](image)

   **Figure 1. Butterfly Life Cycle**

3. These larvae first grew on young Fast Plants. We will now transfer them to brussels sprouts (another member of the cabbage family) in a Brassica Barn (see Figure 4). Setup your Brassica Barn. Do not place paper towel at the bottom. Poke holes in the top lid, and make sure the brussels sprouts leaves are spaced out so the larvae can access them.
4. Use an electronic scale to record the following for time 1 in your data table:
   a. Wet Mass of Brussel Sprouts, Larvae age, Wet Mass of Larvae
5. Label your Brassica Barn and let it sit for 3-4 days

Day 4 or 5

6. Get your Brassica Barn. Use an electronic scale to record the following for time 2:
7. Place your Brassica Barn, with the brussels sprouts and frass, into the incubator to dry out overnight.

Day 6 or 7

8. After at least 48 hours have passed, remove the Brassica Barn from the incubator. Use an electronic scale to record the following:
   a. Dry mass of brussels sprouts, dry mass of frass, dry mass of larvae (optional)
9. Make all calculations for the final column in your data table. Specifically focus on calculating the amount of plant energy consumed, larvae energy production, frass energy lost, and respiration energy estimate.

This learning activity is often fun for students because they learn to handle living animals and they love taking observations. Observing animals is very engaging which helps improve attitudes towards science [Otieno and Wilder (2010), Kur and Heintzmann (2008), Wolf and Fraser (2007), Lord and Orkwiszewski (2007)].
## Results

### Energy Flow from Plants to Butterfly Larvae

<table>
<thead>
<tr>
<th></th>
<th>Time 1</th>
<th>Time 2</th>
<th>Difference between Time 1 &amp; 2 (Growth, Consumed, Gained, Lost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Mass of brussels sprouts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Mass of brussels sprouts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant % Biomass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant Energy (biomass X 4.35kcal/g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant Energy Consumed per Larvae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larva Age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet Mass of All Larvae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet Mass per Individual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Mass per Individual (optional)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larvae % Biomass (calculated or estimated)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Production per Individual (wetmass X % biomass X 5.5kcal/g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Mass of Frass for All Larvae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of Frass per Individual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frass Energy (Frass Mass X 4.76 kcal/g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiration Estimate</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the original lab, they assumed that students could come up with this entire data table on their own. Students often struggle with the energy conversion and are not likely to be successful at setting this up. When activities are not “doable” they become counterproductive [Dawson and Venville (2010)]. This data table scaffolds the data collection process so they are setup for success. Students are still required to conduct other calculations as they are not given everything they need, just enough to set them up for success.

### Other Calculations:
Analysis

1. Why do you think the energy stored per gram of butterfly larva is higher than that of plants? Justify your answer.

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2. Suppose I am a person who is interested in modifying my diet. As an integral part of our ecosystems, I care about the environment and enjoy making energy conscious choices. What type of diet would you recommend to be more energy efficient to an ecosystem, plant-rich or animal-rich diet? Justify your answer with data from the past 2 labs.

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3. Make a poster that illustrates energy flow in an ecosystem. Use pictures to illustrate the sun, plants, and consumers. Include the data measured and estimated from this lab. Represent your number values in scientific notation. Present it to your fellow classmates, then tape it up outside in the hallway.
This lab builds upon prior knowledge from the previous lab. Once students understand how energy from the sun is captured and stored by plants as organic tissue, students in this lab investigate how that energy moves from producer to consumer in a food chain. Building upon the prior knowledge is a necessary skill for students to make decisions and articulate reason for their decisions [Dawson and Venville (2010), Lewis (2000), Aufschnaiter et al. (2008)]. This lab also requires students to record data and conduct mathematical analyses to convert grams of biomass to kcal of energy. Using math to convert and analyze data is another skill students must learn to promote a population of critical thinkers and consumers of science [Dillon (2009), Their (2010), CCSS Initiative (2011)]. Students also use their mathematical conversions to create a model of energy flow in an ecosystem. Constructing, interpreting and manipulating models is a science practice required by the College Board. When students analyze data, evidence and models to validate hypothesis and form conclusions they are becoming true consumers of science [Dillon (2009), Thier (2010), CCSS Initiative (2011), Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006)]. This lab investigation is another opportunity for students to practice their science literacy skills and really “do” science [Dillon (2009), Thier (2010), CCSS Initiative (2011)].
Investigating Animal Behavior

Background

Animals move in response to many different stimuli. A chemotaxis is a movement in response to the presence of a chemical stimulus. The organism may move toward or away from the chemical stimulus. What benefit would an organism gain by responding to chemicals in their environment? A phototactic response is a movement in response to light. A geotactic response is a movement in response to gravity.

In this lab, you will choose an organism to investigate. Possible choices are minnows, crickets, worms, slugs, pill bugs, or others. Once you have chosen your organism you investigate its movement using a choice chamber that exposes your organism to different substances that you insert into the chamber. Be sure that your chamber is appropriate for choice organism. Crickets, for example can jump and climb cardboard. How are you going to make sure that you are able to observe their movement, yet not allow them to escape? For your independent variable, think about using foods or condiments that might result in a positive or a negative chemotactic response from the organisms. What foods or condiments do you think would attract or repel your organism? Why? Does your organism exhibit a response to light or to gravity? How can you alter the chamber to investigate those variables?

Objectives

• To investigate the relationship between a model organism, and its response to different environmental conditions
• To design a controlled experiment to explore environmental factors that either attract or repel your model organism in the laboratory setting
• To analyze data collected in an experiment in order to identify possible patterns and relationships between environmental factors and a living organism
• To work collaboratively with others in the design and analysis of a controlled experiment
• To connect and apply concepts (With your choice organism as the focal organism, your investigation could pull together many topics, such as genetics, animal behavior, development, plant and animal structures from cells to organs, cell communication, fruit ripening, fermentation, and evolution.)

Choice Organism ________________________________

Independent Variable(s) ________________________________________________________________

Controlled Variables  _________________________________________________________________

Control Group ________________________________________________________________

This lab is another adaptation from one of the AP Biology required labs. The original AP lab requires that students study fruit flies and build their chamber a certain way. This lab is particularly engaging in that it allows the students to pick an
allowing students to pick their own animal and build accordingly is very much an inquiry-based mode to learning science because it promotes a student-centered atmosphere with more critical thinking, problem-solving skills. Students have to think about the animal, analyze its characteristics (how it moves, what it eats, what light conditions or moisture levels it prefers, etc.) and consider those characteristics when designing their apparatus. This makes for meaningful science learning (Giles, 2006; Otieno and Wilder, 2010; Yeung et al., 2010; Appleton and Lawrence, 2011; Mayer, 2007). Students also observe animal behavior during this lab, which is a very engaging process. Students will observe natural phenomena and analyze their behaviors to evaluate their original hypothesis. This, as Brown et al. (2010), Duschl, Schweingruber, and Shouse, (2006) claim, is an important skill set for a scientifically literate population.

Hypothesis

Hypothesize how your choice organism will respond to each of your environmental stimuli.

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__________________________________________________________________________________________
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Procedure

1. Prepare a choice chamber and label the ends— one end “A” and the other “B” etc. Be sure that your choice chamber is appropriate for your model organism. Be Creative!!
   a. Ex. This choice chamber is appropriate for studying fruit fly behavior. Notice it is clear so it is easy to observe the results. Also, it is completely enclosed so no flies can escape. This chamber only has two sides. You model can have two sides, but it can also have more – up to a max of 4.

2. Lay your choice chamber down on a white surface or piece of paper so that your organisms are easy to see.
3. With your choice chamber empty, place 10-20 of your model organisms into the choice chamber. Give them at least 5 minutes of undisturbed time to settle, and then count (or closely approximate) the number of organisms at each end of your chamber every minute for 10 minutes. This is your control data. Create a data table to record the number of organisms you find at each end (A, B, etc) of the chamber. Be sure to include all of your independent variable in the table.
4. Insert your independent variable into the chamber. Give the organisms at least 5 minutes of undisturbed time, and then collect data again for another 10 minutes. This is your experimental group data.
Results

Quantify the results into a table and express them graphically over time. Your table should include the following:
- Your raw data collected over time
- Standard deviations for each section of your chamber
- Standard error for each section of your chamber
- Chi-Square Analysis for the control and experimental groups.

Share your data with the rest of the class.

_Having student share data with the rest of the class builds a classroom environment of science literacy. Students learn from each other and build knowledge together [Dillon (2009), Thier (2010)]. Scientists do this through publications in science journals and at conferences and symposiums. Modeling this process in the classroom is a great way to improve student attitudes towards science._

Analysis

1. What patterns exist in your data? Complete a chi-square analysis of your results at time 10. Include a null hypothesis. Do this for your experimental group and control group.

Setup your Chi-Square Analysis similar to this:

<table>
<thead>
<tr>
<th>Null Hypothesis:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental Group</td>
</tr>
<tr>
<td>Section A (Bright Light)</td>
</tr>
<tr>
<td>Section B (Natural Light)</td>
</tr>
<tr>
<td>Section C (Dark)</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

2. Were the Chi-Square values different for your experimental group(s) than they were for the control group? What does this mean? Explain
3. Were your hypotheses about the preferences of your organisms supported or not? Justify your answer by referencing your chi-square data.

4. Did any of your organisms display a positive or negative taxis? Provide a biological explanation for why your organisms behaved the way they did.

5. Calculate the standard deviation for each section of your chamber over time. Do the first 2 sections by hand. Use excel to check your work and calculate the rest of the sections. Do this for the control and experimental groups. Include these values in your results.

6. What does a high standard deviation indicate about your data? What does a small standard deviation indicate about your data?
7. Calculate the standard error for each section over time. What is the significance of calculating standard error?

One of the required science practices required by the AP College Board is the ability to calculate standard deviation and use it to draw conclusions about different sets of data. In this lab, students will calculate the standard deviation of the number of organisms in each section over time. Students will also use Microsoft excel to perform t-test analysis to determine if their independent variable is statistically having an effect on the behavior of their animal. Students will use this mathematical analysis to validate their hypothesis, which as Brown et al. (2010), Duschl, Schweingruber and Shouse, (2006) point out is an important skill for all science literate students.
Chapter Four: Summary and Discussion

As the 21st Century rolls forward, there will always be a precedent to maintain a culture of scientifically literate people. The global market is fast-paced and constantly evolving. To keep up, science is continuing to create new technologies and find new avenues for innovation. As these discoveries are made, society moves forward. Recall that economically successful countries like Japan, for example, have roughly 67 times more engineers and scientists per million of population than economically challenged countries like those in Africa (Osborne, Simon and Collins, 2003). In order for the United States to keep up with the technological and scientific demands of an ever-changing global market, it is imperative that American public schools produce scientifically literate graduates. Without it, the United States will undoubtedly struggle to keep up as a world leader.

Unfortunately, however, the typical American student of today has lost interest in science (Dean, 2007; Dillon, 2009). This should be an alarming message to science teachers around the country. Science teachers need to find ways to get their students engaged and interested and engaged in science again. Research by Quinn and Lyons (2011) explains “if students enjoy school science, remain engaged in it and develop competence, their developing identities are more likely to become consonant with science-related behaviours and choices” (p228). They claim that students’ self-efficacy and self-concept are strongly correlated to student’s attitudes towards science. Furthermore, students with high self-efficacy typically have higher aspirations and motivation to make secondary, post-secondary and career choices in science (Quinn and Lyons, 2011). If students are not interested and engaged in classrooms around the country, it will certainly be difficult for schools to produce future generations of scientifically literate people to keep up with the 21st century demands.

Hence, the importance of producing a population of scientifically literate graduates has not gone unnoticed by state and national organizations. Several states around the country have adopted the Common Core State Standards (CCSS) which call for higher expectations of scientific literacy skills. They claim that too many students are entering college and the workforce only to drop out and be unsuccessful because they don’t have the necessary skills. The College Board has also revamped their science standards. Their goal was to create a curriculum that promotes an application of science skills and deeper understanding of science concepts and practices rather than rote memorization.
of science facts (Common Core State Standards Initiative, 2011; The College Board, 2012). Their goal is to establish a curriculum that will challenge students to “do science” and develop problem solving and science mastery skills.

This project is a tool to challenge students to meet the new educational demands set forth by the CCSS and College Board and consequently produce a population of scientifically literate students that are college and career ready. It is a reconstruction and improvement to the recommended laboratory investigations in the AP Biology curriculum. The lab investigations have been modified to create a more student-centered atmosphere in the classroom. Some methods have been completely replaced because they were not engaging, confusing, or unsafe. Other methods that were mediocre in instructional design were modified to encourage students to be safe, ask questions, think critically, and take ownership of their learning. The traditional teacher-driven verification-based labs that emphasized discovering a remote scientific fact has been replaced with modern student-driven inquiry-based labs that encourage critical thinking, problem-solving, and application of science skills and practices. Placing the student at the center of the learning allows them to think critically, manipulate variables, observe natural phenomena, and take ownership of the learning process (Kur and Heintzmann, 2008; Wolf and Fraser, 2007; Lord and Orkwiszewski, 2006).

Upon successful implementation of this Master’s Thesis Project, students will be better equipped for success in college and the workplace. Rather than leaving high school with an incompetent set of skills, students will enter college and career with adequate problem-solving and critical-thinking skills. More importantly, students will have better attitudes towards science and/or difficult tasks that require problem solving. When faced with a challenging project, lab, or other academic assignment, students will be more apt to think critically about the processes involved. They will be able to brainstorm a list of necessary steps, critically analyze each step, and ultimately determine the most effective and reliable method to complete their assignment. These are the skills that are expected to be successful at the post-secondary level. The benefit of this type of skill set is not only apparent in the classroom, but also extends far beyond into their personal lives and workplace.

Also, woven throughout these lab investigations are several opportunities for students to generate, analyze and incorporate evidence into a scientific conclusion, claim or argument. Writing with evidence and engaging in scientific argumentation are core practices of the scientifically literate student (Brown et al., 2010; Duschl, Schwengruber and Shouse, 2006; McNeil, 2009). When adolescent students leave high school they will eventually have to purchase a car, or
house. They will have to make important choices as to how they power and heat their homes, how they balance their finances, or determine what type of career path is best for them to pursue. All of these choices require students to evaluate and analyze data, observations, or other forms of evidence. They will have to trust in their critical thinking and analytical skills to make the best choice; one that is evidence-based and most likely to positively impact their future. These choices will have a lasting and significant impact on their lives. The learning activities and writing frames established in this thesis project promote the acquisition of skills that will build competence, science literacy, and the ability to make successful choices in life. These skills will pay dividends both inside and outside the classroom and will extend long after class has ended. This capstone project is a pedestal for students to get to that next level. A level where students are college and career ready, critical thinkers who can evaluate, reason and argue scientifically, and above all, are true consumers of science equipped with the necessary skills for success in life.
References


