

INCREASING MENTAL MUSCLE WITH ENGAGING BELL RINGERS IN A
SCIENCE CLASSROOM

by

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DEDICATION

I dedicate my master's work to my wonderful husband Greg, who helped me with all the statistics and my three sons: Alexander, Benjamin and Gregory, who cheered me on to the finished product.

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ABSTRACT

My study utilized bell ringers, which required higher order thinking, would result in increased engagement. Engagement in learning is key for success in scientific literacy, critical thinking and teaching students to be stewards of the environment and bell ringers can be instruments to help build mental muscle. Forty students in two freshman ninth-grade science classes at Lowell High School were studied using a variety of different bell ringers such as misconception probes, bell ringer activities and readings. I measured these gains in pre and post assessments, student surveys, and my own reflections. My treatment groups were two units in which I used bell ringers, which required higher order thinking and my control group had bell ringers which were simple recall of science knowledge. Students in both classes made significant gains in content knowledge in both the control and treatment groups, but the two treatment groups made greater gains. Likert surveys showed that the study resulted little change in student engagement. Student surveys showed students both enjoyed the varied bell ringers and found them helpful in learning material as well as the application of science to real life.

INTRODUCTION AND BACKGROUND

Engagement of your mind is active learning, yet how do we know that our mind is in gear? Gear engagement in your car occurs when you turn the car on and put it in drive or reverse, and the car moves. The chemical energy in the gas is transformed into mechanical energy. We only notice gear disengagement in our car when there is a delay. As science teachers, we desire to foster a learning environment that engages learning. Our goal is to get our student's mental science gears engaged to increase learning. Could cognitively challenging bell ringers be the mechanism to engage my student's minds?

I teach Integrated Science and Engineering to freshmen at the Freshman Academy, which houses only freshmen in a freestanding building of Lowell High School (LHS). LHS is a large inner city school with over 3,000 students in three buildings in Lowell, which is almost an hour north of Boston. The school is diverse both socioeconomically and racially. This is the fourth year that I have been working at Lowell High School in this position. I have been teaching for about twelve years and have taught grades nine through college seniors. I have found that students make too few connections between their learning in science and its application and expect their classwork, at times, to be directly from the textbook. Although some of my students appear physically engaged, I wondered based on past MCAS scores and their current grades whether they were really mentally engaged. MCAS is the science standardized test that all students in Massachusetts need to take to graduate high school.

Was there a mechanism that I could use at the beginning of class to transition to class that would get their mind in gear to learn? I thought of the lessons that I as a

student found engaging and I remembered the “hook” of something that challenged my thinking or made me wonder. When I was in college at Boston University, my organic chemistry professor started a few chemistry classes discussing the mechanism of how chemical warfare nerve agents work, how antidotes needed to be administered quickly and how once the receptor was bound, enzyme inactivation is irreversible. This practical application of abstract organic chemistry intrigued me. In my teaching, I wondered if I could provide my students with practical applications of science to their daily lives so that perhaps they might pursue a science, technology, engineering, or math (STEM) career or at least be challenged in their thinking about how science works in their everyday lives. At the minimum the bell ringers should help create an environment where students are held accountable for choosing a position and backing that position up with evidence.

Lowell Public Schools is an inner city school with 74% low-income students. A few years ago this high percentage of low-income students landed Lowell Public Schools free-meals for both breakfast and lunch. Superintendent Khelfaoui was quoted in the Lowell Sun as saying “This is going to make a difference in academics...your head works better when you get a full stomach” (Lowell Sun, 2015). Could bell ringers, which set the tone for class and help focus students’ attention, be the method to engage their minds as well. I chose to explore in my research whether utilizing a variety of cognitively engaging “bell ringers” would result in more engagement.

The bell ringers could help create cognitive dissonance in which students need to make sense of their new learning in terms of what they already know to be true should

increase engagement. Having my students' misconceptions challenged in daily bell ringers and/or their making science real to their lives should increase student engagement, interest and mastery in science.

Lowell is a city with rivers and canals that in the past powered factories, which made massive quantities of goods such as textiles and today it is a city that struggling to find its' niche again. The rivers provided hydropower to the factories and immigrants moved to Lowell to run the factories. Immigrants still come to the city to live and to work. Unfortunately, the industrial revolution has passed, technology has changed, and now Lowell has a high poverty rate of twenty-one percent, which is higher than the national average. Lowell was founded in 1821 and was named after Francis Cabot Lowell, who revolutionized the cotton manufacturing process by putting it all in one building. The town of Lowell, which then became a city, is located next to the powerful Merrimack River utilizes the kinetic energy provided by the Pawtucket waterfalls to power the mills. "The water... generated enough horsepower to support 44 mills and their print works, machine shops and whatever other machinery was necessary" (Lorenzo, 2009). Lowell was a model example of the factory city with mills, dormitories, and churches. Unfortunately hydropower gave way to electric power, mills closed, the population decreased and looked elsewhere for other sources of income.

The mills have all closed, but the mighty Merrimack River still flows and so does the flow of people as immigrants still flock to the city. LHS is a public high school located in Lowell, which is about forty-five minutes north of Boston. The school is diversity ethnically and socioeconomically. LHS reflects the diversity of the city where it

is located with 11% African American, 32% Asian, 25% Hispanic and 29% White students. Unlike most other high schools in the nation, the high school was an integrated school from its' first opening in 1831 and was the first co-educational high school in the nation and continues to be today. Up until 1831 there was only education to eighth grade, which was paid for by the mill owners of what then was the town of Lowell. The issue of expanding education to include a high school was put to the citizens' vote. The vote was positive in favor of educating students through high school. Lowell was the second community in Massachusetts to have a high school in 1831. "It was a bold decision that I think created the 'can do attitude' that continues today" (Lowell Sun, 2017). LHS is a large inner city school comprised of over three thousand students housed in three separate buildings. The school is diverse socioeconomically with both higher and lower income families in attendance. A significant number of LHS students are recent immigrants and are English as a second language learner's (ELL). English as a second language learner's represents 37.2% of the students at Lowell High School. LHS reflects the diversity of the community with students from over fifty countries who speak sixty different languages. Bell ringers cut across the many cultures like the river that flows past their classrooms.

One mill in Lowell, called the Boott Mills, which in the past produced textiles, is now a museum. The Boott Mills Museum is next to the Freshman Academy where I teach science to freshmen at Lowell High School. While the Boott Mills were in operation, bells called the workers to work like the bell today tells students today to change classes.

One way of starting class, like starting an engine, is to use class starters called bell ringers, which set the tone for the class and help focus the classes' attention. Examples of bell ringers include activities such as answer questions in a misconception probe in which they have to choose a position and back it up with evidence then discuss their responses with their table. As a class, we could do a lab that addresses that misconception such as seedlings lab in which they observe the seeds daily as bell ringers to have first-hand knowledge of how seeds sprout and grow roots. As a teacher, I desire to help my students have a solid foundation in science and one mechanism to facilitate that is to make them curious and to begin each day having them think about what they know and how it “fits” with what they are being taught. Engagement in learning starts with bell ringers that require higher order thinking. Does using a variety of bell ringers increase engagement and mastery learning?

CONCEPTUAL FRAMEWORK

Science Literacy

Scientific literacy benefits both the individual student as well as our society as a whole and critical thinking is a key component of this. Therefore, science classes need to be taught in a way that will encourage student engagement in scientific thinking and in science in general. The application of science and math to real life situations will, hopefully, put their minds into gear and keep them on the road to success. In Europe, the curriculum has been re-designed to engage learning in science towards scientific literacy in which they make connections with scientific thought, the world around them and topics such as energy and technology (Coll, 2009). This scientific literacy is practical,

civic and cultural. This three pronged approach to science literacy engages students in science by making science real by solving real world problems, providing opportunities for debates and guides them in seeing themselves as stewards of the environment. Researchers found that even though the content was re-designed teachers were still focused on teaching content and not on crosscutting concepts and scientific thinking. As teachers we need to facilitate the learning process by helping students learn to think critically and to have a framework in which to place their science learning.

Interest in Content drives Motivation to Learn

Research has shown that student interest increases motivation, which in turn increases their recall of information (Koksal, 2013). In science courses much of the content can be abstract and difficult to assimilate due to students not being able to make connections to this content knowledge. Many studies have shown that there is a relationship between how science is taught and student's attitudes towards science (Sukarjita, 2014). Students learn science content and need to provide the context of how that content fits in the world around them. If teachers provide thought provoking bell ringers, this could increase motivation, mastery and staying the "course" of finishing high school.

Motivation in Learning Science

Biology is the study of life and although the topic is introduced in the elementary years, the focus on learning and applying biology knowledge does not happen until high school. Motivation is the biggest factor in learning biology (Koksal, 2013). One hundred and eighty high school students in Turkey were used as study subjects in evaluating "task

value” instrument, self-efficacy and test anxiety scales. The researchers found that motivation guides and directs a focus, which results in learning. Biology students need to be active learners and have the ability to construct knowledge that is applicable to their daily life. A positive correlation was found with intrinsic motivation, extrinsic motivation and the control of learning beliefs. If teachers are able to provide probing questions that pique student interest and guide student learning, this may result in more learning.

Student Stewards of the Environment

Students have a natural curiosity about the environment and models of teaching have been developed to encourage scientific discourse. One example is the MOTORIC model (motivation, observation, talking, orientation, reinforcement and implementation and confirmation). Students need to be motivated to learn science, have the skills to make observations in science, reinforce their knowledge and then have an application of that information. Students need to learn about natural resources because they are going to become stewards of nature (Sukarjita, 2014). Children can be taught to protect the environment at an early age, which will provide a foundation for being environmental stewards as they grow up. Using the MOTRIC model, students were taught practical science applications of world problems such as waste management, pollution and conservation. Topics they discussed included how deforestation resulted in erosion and mudslides. They were taught with a three-pronged approach that included, a character approach, a contextual approach and a multimedia approach. The students were able to make connections between what they are learning and the world around them. Bell ringers that have practical STEM applications and misconception probes that challenge

their thinking could help students become more engaged in their science content knowledge and in being active stewards of the environment.

Intrinsic Motivation and Learning

Learning because students are motivated to learn is a key part of how we engage our students. We seek to make our teaching meaningful so that the students find enjoyment in learning. Researchers administered an Intrinsic Motivation Inventory to see how many students were low in intrinsic motivation. They found a correlation between low intrinsic motivation and lower class scores (Augustyniak, 2016). We need to find ways to motivate students so that they can help us find solutions to the challenges we face as a society. Bell ringers, which engage students in active thinking, can be a key to learning both for individuals and our society. Students will learn to view science as a way of thinking where they can be engaged in the world around them, rather than merely learning random abstract concepts, which have no relevance to them. This hopefully will increase their motivation which will not only have them stay in school, but be active in their school and local community.

Motivation and Attitude

Motivation and attitude affect student engagement in learning. If classes are begun in a way that increases student motivation then that can directly affect their learning. “The roots of interest in engagement are, in least in part, driven by the desire to enhance student learning” (Christenson, S.L. et. al, 2012) Teachers, administrators and teachers desire to create an environment where students can learn and want to learn. However, when trying to establish what engagement is and how engagement can be

affected becomes more nebulous like trying to catch a cloud. Researches have come to a consensus what the minimum threshold of engagement is made up of: class participation, affect and also cognitive engagement. Bell ringers require class participation, as each student is responsible for their own work, a discussion of their thoughts, which hopefully will result in their mind being engaged like a gear in an engine.

Engagement in Middle School Predictive of Future Success

As students grow and develop the concepts that they find meaningful and of interest become topics that they potentially pursue as they grow older. Middle school has not been studied as extensively as high school has in terms of engagement, but it is a formative time like freshmen year in high school when students are still making decisions about their futures and deciding if they can find success in science. “School related variables such as academic student engagement, perceptions, attitudes and knowledge of the role of math/science achievement in future career opportunities that can be influenced and amenable to change by educational institutions.”(Singh, 2002) Research has shown that when students find success in science and see themselves involved in science their interest in science increases. Bell ringers, which make science interesting, should be an effective method in engaging students in higher order learning and hopefully future thinking of careers in STEM or STEM related fields in which there is a huge need.

Making Learning Meaningful

Research into active learning has found that students are more engaged when learning is made meaningful. The teacher needs to gain a student’s attention, make the student curious, make material relevant to a student’s life, help provide them confidence

to complete a task and the satisfaction in completing the task. ARCS model of attention, curiosity, relevance, confidence and satisfaction blends well with the concept of starting a class with a bell ringer, which should do the ARCS method. Using bell ringers or bell ringers that follow the ARCS model I expect should increase engagement (Keller, 1987). Bell ringers are short tasks with quick feedback which affirms student's value in the classroom and that they are a contributor and are valued.

Cognitively challenging tasks

The beginning of class is the time in which you can capture students' attention with goals for the day and opportunities to provide them with a task that requires more cognitive attention and therefore more engagement. Students can be provided with a bell ringer in which they have to make a claim and back up their claim with reasoning. (Deana, 2015) Since students need to make a claim and then back up their claim with evidence researchers found that students were more engaged. Since they are more cognitively engaged, their interest in their class and their school increases which is a positive outcome. This critical thinking extends beyond the classroom as students take these skills into the working world.

Confusion and Engagement

Another mechanism that researchers have found that increases engagement is cognitive dissonance. When something does not fit in with what a person "knows to be true," students want to sort out the difference, which causes their mind to be more engaged. This misfit of information creates a "confusion which has been shown to play a catalyzing role for promoting engagement and learning in science" (D'Mello, 2014).

Bell ringers, which include misconception probes could create cognitive dissonance and therefore create an environment that aids in learning. Since there is an impetus to change, the mind wants to reconstruct order to the disorder and teachers can help facilitate this by providing the framework in their content teaching to aid in this.

Tenacity and Mental Muscle

Tenacity, the ability to hold fast even if the task seems undoable, is a skill we need to teach students and each class should start with a mental warm up to help them build their mental muscle. “The adversity that children experience both in and out of school can affect their psychology, with consequences for learning...we can directly help students to become more motivated and successful learners.” (Dweck, 2014) Researchers have found that students need to be challenged academically and that students need to have high standards set for them, even those who are at risk of dropping out. One of the issues this providing students with academically challenging tasks is that the task is often complex itself with multiple steps. Bell ringers, which are cognitively challenging yet attainable, can be a positive impetus for academic success. Bell ringers are a task that is short in duration, which makes it attainable and therefore increases motivation.

METHODOLOGY

Project Treatment

The purpose of this study was to see if using cognitively engaging bell ringers increased student engagement and learning. A total of 38 freshman science students in two freshmen classes participated in this study. Montana State University Institutional Review Board approved the exemption of this research project and guidelines were

followed for working with human subjects (Appendix A). The classroom research project occurred during a six-week period beginning in January as the freshman science teachers started the biology part of the integrated science curriculum, which includes a unit on introduction to biology, a unit on chemistry and a unit on cell biology. Students from one college level integrated science class and one high honors level integrated science class were the study groups. The ethnicity of my classes is reflective of the school as a whole. My science classes are heterogeneous in nationality and gender. Class sizes range from 23 in high honors (Block 3) to 15 in college preparatory (Block 5). Both classes have English language learners and native English speaking students as well as both male and female students.

The capstone research study focused on seeing if cognitively engaging bell ringers, which require higher order thinking and relate science to real world issues, resulted in more engagement. There were two units of treatment and one unit of a control group. The treatment groups had a variety of higher order engaging bell ringers and the control group had traditional bell ringers, which involved recalling content knowledge. My primary research question is:

Does utilizing a variety of bell ringers, which require higher order thinking, in science class increase student engagement and mastery learning?

Sub questions:

1. What are the effects of engaging bell ringers on student engagement?
2. What are the effects of engaging bell ringers on science content knowledge?

Table 1 shows the data triangulation matrix of data that was collected for each of my two focus questions. A Likert survey, bell ringers, pre and post assessments and a teacher journal provided both qualitative and quantitative data. When I analyzed my data, I looked to see if there were greater gains in the post assessments in the two treatment groups than in the control group and if student's Likert survey scores improved. I interviewed students individually using questions from the Likert survey to provide qualitative data.

Table 1
Data Triangulation Matrix

Focus Questions:	Likert survey	Bell ringers	Pre-post assessments	Teacher journal
What are the effects of engaging bell ringers on science content knowledge	X	X	X	X
What are the effects of engaging bell ringers on student engagement	X	X	X	X

DATA COLLECTION

Prior to data collection student assessment data were collected and one major source of science content knowledge is their 8th grade science MCAS scores. There are four levels of MCAS data: advanced, proficient needs improvement, and warning. To collect data on student engagement with different bell ringers, a pre and post Likert

student confidence survey was employed after each treatment and control group. An example of the Likert survey is included in Appendix B. My survey was adapted from the Student Engagement in Schools Questionnaire (SESQ) and the Teacher Engagement Report Form-New (TERF-N), which are surveys, which were created to assess student engagement. I included both a quantitative score in that the students needed to choose a value for different engagement questions, a qualitative score in which students had to answer short prompts and student interviews. I also recorded teacher observations of my classes during both the treatment and control groups.

I administered a teacher generated pre-assessment and a post assessment at the beginning and ending of each treatment group (approximately two weeks). The initial treatment group included an introductory unit of biology with engaging bell ringers. The control group was a unit, in which I used simple recall questions for the bell ringers. The next treatment group was a biology unit on cells. I hoped to see more engagement in the treatment groups in both engagement and in test scores.

Data Collection Instruments

My treatment groups: Each treatment group had a variety of cognitively engaging bell ringers. One type of bell ringer I used in the two treatment groups was a misconception probe. A misconception probe is a series of questions and/or diagrams created to show student misunderstandings. I used the misconception probe as a bell ringer in which students have to explain their reasoning in written form answering a probing question. The probes are designed to provide insights into student misconceptions. In the initial treatment group, which I named introduction to biology

unit, for the probe, I had the students answer the questions individually and then discuss them as a table. I chose different misconception probes that related to current unit content topics find out what misconceptions my students had about each topic prior to teaching the topics. Examples of the misconception probes I employed in my classroom are in Appendix C. Topics included were: what are the characteristics of life, what does a seed need and where does the mass in an oak tree come from.

Another example of a bell ringer that I used were bell ringers in which students needed to collect data daily as their warm up activity. My students collected data on their own seedling they “wore to class daily.” Each student was given a radish seed and each student had to decide what variable they would change that would affect the seed germination of their seed and daily as their bell ringer make observations. The students then planted their radish seeds in plastic microfuge tubes with water and dirt and were responsible for bringing their seedling to class to make observations about the germination. After five days of data collection, the students used their qualitative and quantitative data to support or not support their hypothesis. Since my students had to make quantitative and qualitative observations daily, I hoped to arouse student’s wonderings about seed germination.

After the initial introduction to biology unit, which was the initial treatment unit, I did a unit of traditional bell ringers in which I asked a daily content recall questions. I used the science content from the prior day or current unit to ask questions which the students needed to answer individually at the beginning of class and then pass them in. We would then discuss the question and answers as a group.

The next treatment group was a cells unit in which I used a variety of misconception probes, readings and activities. One misconception probe was Eureka and had the students choose different options and then explain how the option fit with the form and function of a unicellular organism. I did a reading from a book called “the Making of the Atomic Bomb.” The reading was about chemical warfare agents such as mustard gas, which diffused into trenches to cause pain and suffering to the soldiers. The mustard gas would seep into the soles of soldiers’ shoes. I related this and how my grandfather was gassed in World War II and that they didn’t expect him to survive or to be able to have children which he did. My students were instructed to relate the reading to what we were learning in science class. This was an opportunity for my students to see the practical deadly applications of chemical warfare agents and chemistry. I also had my students answer probing questions of my own such as “what evidence was there of a chemical reaction in the enzymes lab.” I also read a short article “Don’t fry this at home” an article about cooking eels and procrastination in writing, which most students could relate to as many struggle with procrastination at some point. My students then had to relate the reading to what we were learning about in class. Another bell ringer that I created was having my students listen to a Michael Dickinson professor at California Institute of Technology discuss on a Ted Talk about how fly flies. My students then chose a microscope slide that we had in our school and they had to research the form and function of that organism. They then made a poster with the information on form and function from a microscopic view and a macroscopic view (Appendix D)

Table 2 shows the variety of bell ringers that I used for my two treatment groups. In the introduction to biology control group I implemented a variety of misconception probes so that I could learn what misconceptions my students had prior to starting a unit. I had students make a hypothesis and collect data about the germination of a radish seed. In the cellular biology treatment group I used misconception probes, probing questions, readings and a bell ringer that led into a two day activity. My students watched a short Ted Talk about how a fly flies, chose a microscope slide of an organism and then made a poster of what they learned about the form and function of their organism from a macroscopic to a microscopic view.

Table 2

Two Treatment Groups Introduction to Biology and Cellular Biology

Introduction to Biology	Cellular Biology
Is it Alive Misconception Probe	What evidence was there of a chemical reaction in the enzymes lab?
Needs of seeds Misconception Probe	Eureka- Cells Misconception Probe
Food for the plants Misconception Probe	Is it a Plant Misconception Probe
Is a chicken egg a cell?	Making of the atomic bomb-mustard gas reading and questions-diffusion
The Mighty Oak Misconception Probe	Grape question
Germinating seeds-5 days duration	Form and Function-You Tube Video, bell ringer and activity
	Atoms misconception probe
	Sequoia Misconception Probe
	“Don’t fry this at home” article

Chemistry Unit (control group)

My control group was a chemistry unit in which I used traditional labs and warm ups which just ask for basic recall of facts. I asked questions that related to the prior class's content. For example "what is the monomer of the macromolecule carbohydrates and what is it used for in the human body." There were simple recall questions that could be answered with recent notes. My students wrote their answers on an index card and passed it in. As a group, we discussed the answer.

My teacher reflection journal was my daily notes about how students responded to their bell ringer prompts both individually and as a group. I observed how they did generally, what key words came up as they answered the misconception prompts and the overall atmosphere of the class. I adjusted my teaching the following day based on data collected from the bell ringers.

DATA AND ANALYSIS

I teach four integrated science and engineering classes and chose to do research on only two of the four classes as visually they would appear to be engaged. My reasoning for choosing those two classes was that the students in those two classes exhibit signs of engagement: they are in school, they are on time for school, and they are on time for class. Both classes are prepared for class with their homework done with a pencil/pen in hand. Specifically, Block 3 is a high honors class and Block 5 is a college level class. If you observed both classes you would conclude that these are hardworking and mentally engaged in learning. The students are involved in clubs and activities such as the Freshman Academy STEM club of which I am one of the two advisors. They participate in a variety of after school activities such as sports, culinary club and plays.

Visually my students appear engaged, but are they cognitively engaged and could I engage them further with mentally challenging bell ringers.

My investigation focused on whether engaging bell ringers would result in more cognitive engagement, which would be reflected in student academic achievement, daily bell ringers, in my teacher journal and Likert surveys. Students would see science as relatable to their daily lives and think deeper than simply answering recall questions.

I observed significant academic gains in both classes in my classroom research project as shown in (Figure 1). In looking at the overall scores from the Block 3 the high honors showed greater post assessment gains in content knowledge. Block 3 is a high honors class, which had significant gains in both treatment groups as well as in the control group Chemistry. Since my students had some prior content knowledge about biology, but little to no content knowledge about chemistry, the gain in chemistry knowledge was as expected. My block 5 class is a college level, which you can observe academically has lower assessment scores. While Block 5 had gains the gains were not as pronounced as Block 3, the gains were significant in both treatment groups intro to biology and cell biology. Academically based on test scores the bell ringers increased engagement.

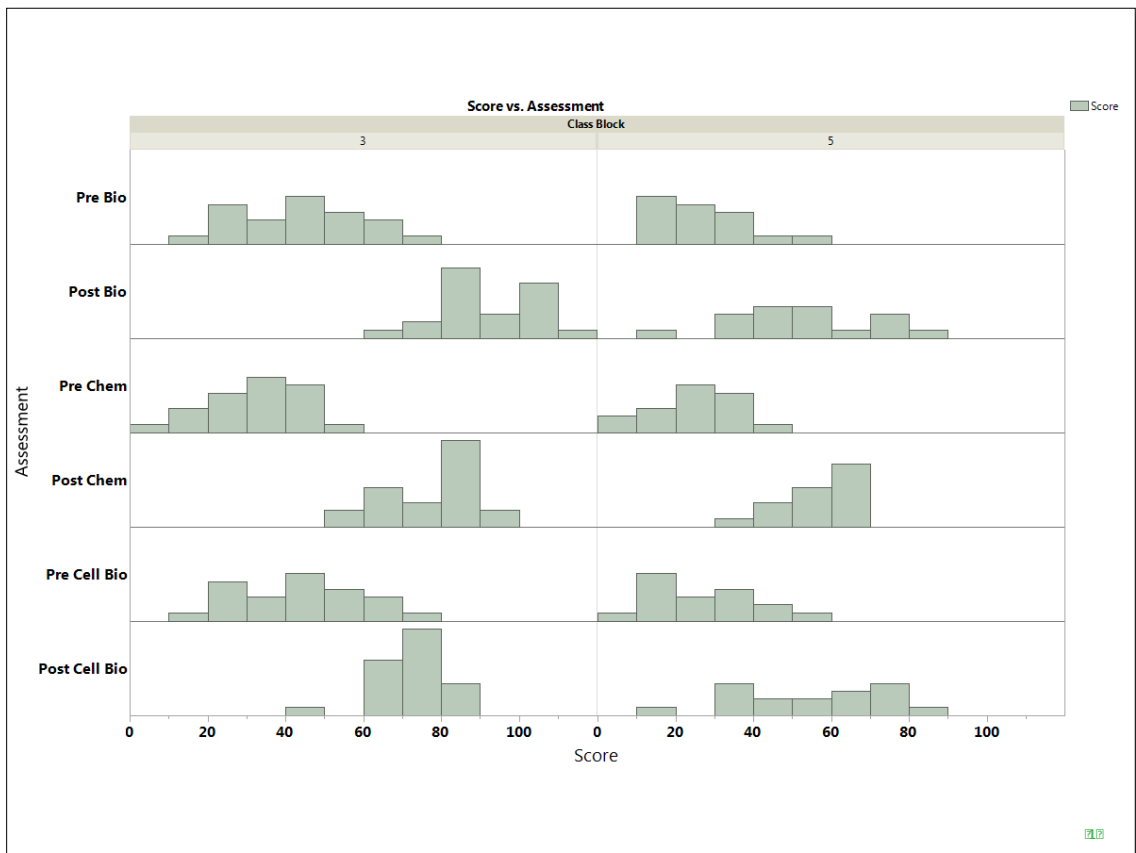


Figure 1. Pre and post assessment scores, (Block 3 $N=23$, Block 5 $N=17$).

I also recorded a teacher journal the responses the students wrote for their explanation of their choices in their misconception probes in the treatment group and found that some of the concepts that my students were confused on similar. In block 3 phrases that were repeated as an explanation of my plants misconception probe were that plants needed to start as seeds, need natural amenities to grow and water, soil and air. Students were solid writers, had some content knowledge, but didn't always answer the question asked and answered instead the related information that they knew about said topic. Block 3 used better vocabulary to describe their reasoning, but as a group was often just as confused about the misconception probe as Block 5. In block 5 students wrote sentences such as "I chose these answers based on my knowledge of how plants

make food.” This was one of the better initial explanations for the initial rounds of misconception probes. Another student in block 5 wrote in his explanation that he chose certain choices as plants because “plants produce oxygen which allows us to breath.” This student provided solid science knowledge in the content area of what plants provide us, but did not answer the question of “describe the rule or reasoning you used to decide if something is a plant.” Another student’s explanation for their reasoning was “I thought of what grows from the ground.” Based on these observations for both block 3 and block 5 misconception probes I reflected that I needed to show students examples of aquatic plants and also help them work on answering the question asked on not ancillary information about plants.

When looking at pre and post assessment scores by block and MCAS proficiency, as shown in (Figure 2) a trend appears that there were greater gains in post assessment with the higher-level class, which is Block 3. Block 5 has a higher number of lower performing students on their MCAS than Block 3. Block 5 also has a higher number of ELL students. The students in both blocks who were in the warning level on MCAS scored lower overall on their pre and post assessments. Students who had a passing score on their MCAS had a much stronger response to the engaging bell ringers than students who had a failing score on their MCAS.

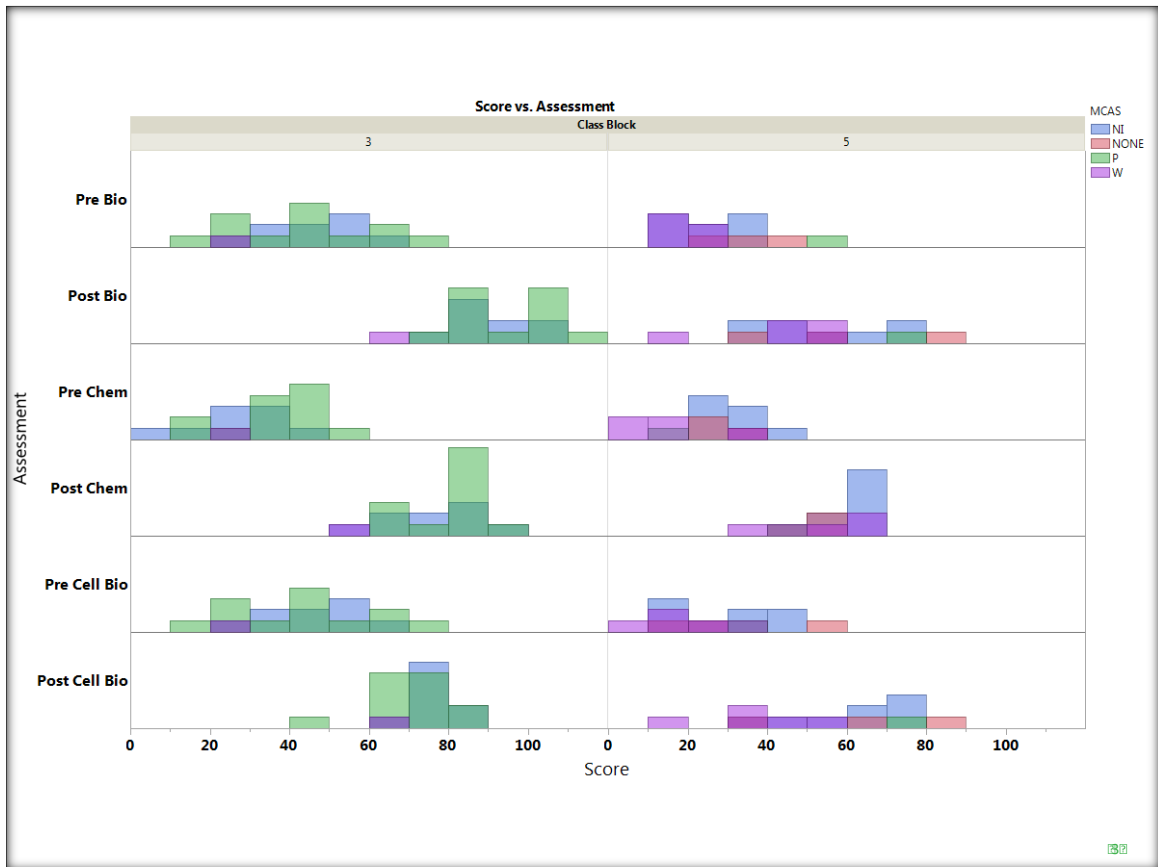


Figure 2 Pre and post assessment scores correlated with student MCAS data ($N=23$) and ($N=17$).

In reviewing data from my students prior to starting high school I was surprised that, not all of my students in my high honors class had been proficient in their MCAS scores in middle school. My freshmen Integrated Science class is now a formative year of science, which includes physics, chemistry and biology to help prepare the students to pass their Biology MCAS, which is a requirement of graduation. Our department head wanted us to start using our beginning class time to have students write responses to MCAS questions as our students historically did worse on the open response section of the MCAS. Using bell ringers that are MCAS questions require thinking, but can be dry and static. If I used bell ringers on topics such as diffusion and how it is integral to their

everyday lives, and relate it to abstract science such as how scientists used this same diffusion mechanism in making mustard gas to cause the most harm and discomfort, this should result in more engagement.

One issue that quickly presented itself with my initial analysis was that I should change the number of questions on my Likert survey to 12 with four questions of each type of engagement: affective (liking for learning), behavior (effort and persist) and cognitive engagement. Other data points that I have going into this research are my students' current ELL status as well as their performance on their 8th grade science tests. What was surprising to me was that not all of my high honors students, Block 3, had passed the 8th grade science MCAS. One of the areas they appear to be weak on in the MCAS is the short answer portion. Students need to practice using scientific thinking to answer science questions. Hopefully, engaging bell ringers will not only captivate their interest more in science, but will result in them passing a required science MCAS for 10th graders.

My initial analysis of pre and post data by English language learners and gender showed no significant differences, but after additional analysis there was an increase in bell ringer scores and a greater increase in the post assessment scores for all the treatment groups. In analyzing my data based on ELL versus non-ELL, Block 3 in the first treatment group Introduction to biology unit my high honors class, non-ELL students improved more than ELL students using warm up grades as the unit of measure. This would indicate that there are more challenges than science content in improving ELL scores. There was no significant difference between boys and girls. When thinking back

to some of the titles of my misconception probe bell ringers such as “A grape Question,” which is a play on words about what is a great question and was probing their understanding of energy transfer some of my students especially my ELL students had to have the title explained to them. It was a humorous moment. All of my data collection was skewed due to weekly snowstorms in which school was delayed by several hours or cancelled for several days, as roads even in the Northeast, had had to be cleared of snow and ice. There were also multiple issues with heat in my building and then a gas leak, which resulted in my school being evacuated and then closed for several days for repairs. Almost weekly during my treatment and control group data gathering time period there were school closings due to weather, delays, and closing due to facility issues. This would be a confounding factor, as bell ringers need to be consistent and repetitive to sustain the gains in reprogramming their thinking in focus in learning. As a result of all these delays and no school days, Lowell Public Schools will be in session until two days before I leave for my capstone presentation week. Although statistically there were no differences for ELL or for gender in my data, the bell ringers did help academically.

Engagement in Likert student surveys yielded positive qualitative results. Both my coworkers, and myself noticed students were “talking about science” outside of class and in the hallway with treatment groups. When my students were responsible for bringing seedlings to class daily, they commented “I had a hard time remembering my seedling and cared for it by putting it in the window as seeds need sunlight to germinate.” Another student remarked that “she left he seedling at home with daycare as she had forgotten it.” Another student said “he mom overwatered her seedling which resulted in

it not sprouting. It was an amusing moment in which the student agreed with me that her mom was trying to be too helpful.” Statistically the data with the Likert survey showed no noticeable patterns. Increased engagement as measured by Likert surveys in such a short window of surveys could be too short a window to statistically see a difference.

As I reflected after the “introduction” to biology treatment group daily, I noticed that the misconception probes introduced me to more misconceptions that the students had that were greater than what I had expected. Some concepts such as mass of an object increasing were not the objective of my misconception probe, but it was a misconception that was presented as I evaluated my student’s responses. My students were convinced that the seedlings needed sunlight to germinate and therefore some remarked that they put their microfuge tube filled with a radish seedling on their windowsill at home so that it could get enough sunlight. We discussed what needs seeds have and noted that the students who did not specifically keep their seeds in the sun sprouted just as well as the seeds that were put in the sun each day when they arrived home. This brought up another point of having many variables in an experiment and why researchers try to control for as many variables as they can to show a cause and effect. The bell ringers, which took up just a short portion of the class time, were effective in showing me both the misconceptions I was trying to address as well as many other science misconceptions my students had.

The bell ringers for my control unit on chemistry the students noticed immediately that the bell ringers were simple recall, but they found the daily bell ringers to be like daily quizzes. I did not think about how difficult simple recall questions could

be to my students nor did I think about how my students enjoyed finding success in doing well in their bell ringers. Science is a very abstract topic so the topic specific bell ringers became challenging as well as boring to the students as they did not recall the material from the day before and also their learning had no meaning to them. Some students in their Likert survey said the “bell ringers help me focus on what we are learning.” Others said they found the bell ringers from the control group to be predictive and boring. The students who got the answer correct did so quickly and had to wait and the students who did not have the correct answer were just visibly frustrated.

In my next treatment group I added a twist to the misconception probes that the students needed to discuss their answers to the misconception probes. Unfortunately many groups stuck with the wrong answer as the student at their table who they perceived to be “knowledgeable” were the leader of the knowledge even though they themselves had read, hear or had discussed other ideas. This was disappointing to me but also a revelation in thinking about how to elicit student responses that are individual composites and that everyone in a group has a voice. I implemented having the students use white boards to write summaries of what they had written in their bell ringers. This forced my students to be at least somewhat self-reflective and to think about what they wrote and what others did around them. With the white boards they were more willing to make changes, as they were easier to just erase and to write over.

The bell ringer scores for the cell biology unit over time are shown in (Figure 3). At this point in my research, my students have done bell ringers for three units a treatment group, a control group and a treatment group. The data shows that the bell

ringer scores increase over time. This would show that students do well with familiarity of doing bell ringers and also are building mental muscle.

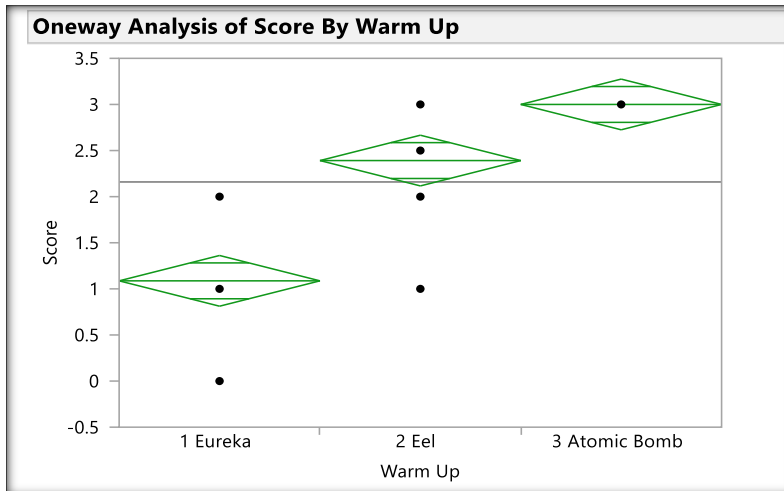


Figure 3. Bell ringer scores for introduction to biology, ($N=38$).

The bell ringer scores shown in (Figure 4) are increasing over time for the second treatment group cells for all students: blocks 3 and 5. Initial analysis of gender and ELL showed no marked difference for any of the treatment groups. As I had grades the bell ringers, but did not assign a grade to the students and the scores still went up for both classes is a good sign that the bell ringers were effective in engaging students in learning.

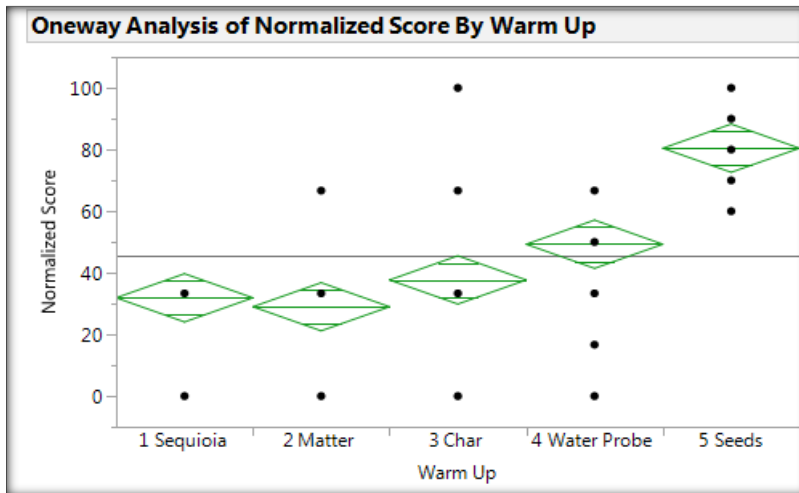


Figure 4. Bell ringer scores cell biology treatment, ($N=38$).

My students were excited about the biology portion of their freshman Integrated Science class, as they had some prior knowledge of biology unlike the physics and chemistry units, which, we began the year with. The weather was a weekly battle to get to school and have school. Each week we had a major snowstorm with weather related delays and cancellations. Living in the northeast we are used to snow but weekly major northeastern storms, which had over a foot of snow each became a stressor to all. Several storms resulted in extensive power outages. As a result, having consistent bell ringers and a consistency to my teaching was a challenge. Some days I would have only half of my classes due to weather related delays. In spite of this my students did some good thinking as evidenced by their increased post assessment scores shown in Figure 1 and Figure 3.

My student interviews were conducted after both treatment groups were done and I explained to each student as I interviewed them that some bell ringers were just simple recall in the chemistry unit, but that the other two units I had tried to give them bell ringers that were more mentally challenging. My students' responses were not what I

expected either. Some of the students liked the simple recall questions that I used, in the control group, as they liked “not having to think much and to have a review.” Most students liked the more challenging bell ringers that involved misconception probes, readings and activities. They liked the opportunity to discuss science with their classmates and to reach a group consensus after starting individually. They said that the discussion helped them “learn science better.” Many students said they really enjoyed growing seedlings in the microfuge tube. They had to bring their seedling to class daily and make observations to receive credit for the assignment as their bell ringer. The students like the “hands on” component and also that they could visually see the roots and stem forming through the opaque microfuge tube. Some of my students with higher grades liked the simple recall of content, as it would provide him with a good grade, whereas “the probes were difficult and too open ended at times and I wasn’t sure I got the right answer.” Another high scoring student said, “I like the simple recall bell ringers as going over it drills the content into my head. Being more independent thinking at the high school level can be difficult at times.” Another also liked the simple recall of the content recall bell ringers as he finds science difficult at times and the forced review through the bell ringer helped cement the science in his head as he said “science is really hard.” Other students mentioned they really liked that the probes were “open ended as it made you think and made the class more interesting.” Many said that they liked the open-ended misconception probes as they were forced to discuss science and to learn from each other as the answer required thinking. One student said, “when I got what the misconception probe was about it really helped me.”

INTERPRETATION AND CONCLUSION

My classroom research project focused if the use of bell ringers, which required higher order thinking, increased engagement. I measured these gains in pre and post assessments, student surveys, and my own reflections. My treatment groups were two units in which I used bell ringers which required higher order thinking, and a control group that had simple recall of science knowledge. I found the use of mentally challenging bell ringers increased student's mental muscle and student's attitude towards science and science class. My lower level students found that they could have success with the short bell ringers that they didn't have on longer assignments. One ELL student remarked "the bell ringers were the only part of class that I got." Students enjoyed the discussion and helped them in understanding science concepts. Through daily bell ringers students learned how to think critically and how to apply science and scientific thinking to their daily lives.

Even after my study ended I continued the use of cognitively challenging bell ringers as I found them to be a useful tool to engage students in learning as well as to foster conversations. The students found that the bell ringers made science real to their everyday lives. The first Friday in May was May 4th and my bell ringer was "what does may fourth mean and how does this saying relate to science and specifically photosynthesis." Students were amused or confused with the play on words with fourth and the force be with you and also reinforced the central concept of science that there are forces acting in nature other than basic gravity. Students recognized that the sun is a force that provides solar energy to all life on Earth. I followed up this warm up with a

photosynthesis worksheet that related the dark and light reactions in photosynthesis to the light and “dark side” in Star Wars. This use of humor in the classroom added to the positive learning environment.

VALUE

As I continue to teach science to freshmen and help them connect their scientific learning with life in general, I wonder how to create challenging bell ringers engage students but are not overwhelming to them. I was surprised in my research especially in the use of misconception probes that students had many more misconceptions than I anticipated. I also was surprised at how hard it was for my students to summarize the point of an article and to relate this information to science. The bell ringers were a frequent opportunity to relate science to their everyday lives. I am considering providing them with the article that I read from and also choosing simpler articles with lower level vocabulary. I could import the article into word and find the reading level of the article.

One of the greatest benefits to my study was the formative feedback I received on my teaching and their learning. Recognizing their multitude of misconceptions early in the unit provided me with a greater opportunity to dispel some of their learning myths by lab activities such as the seedling bell ringer observations. They had direct evidence of the needs of seeds by observing their own seedling as well as others as the seeds germinated. Since the students had daily simple bell ringers which included direct observations of living things, they could observe whether their hypothesis was supported or not. This gave them a simple opportunity to “do science.” Since I used bell ringers daily, students looked forward to them as the bell ringers were simple tasks that all

students could be successful in completing. This concept of making science doable to all students at all levels was a good take home message for me as a teacher.

I was also surprised to learn that even though students observed actual plant and animal cells they continued misconceptions that they had. One example of this is that in the Eureka misconception probe many students included that “scientists could observe lungs in a living unicellular organism when they had observed unicellular organisms both living and “fixed” that did not have lungs.” In one microscope lab we did we used *Tetrahymena*, a single ciliated protist, which did not have lungs, but was transparent. My students have seen “the real deal” or organisms that are unicellular and eukaryotic, yet their misconceptions persist. Engaging bell ringers did increase engagement and created a positive learning environment in my science classroom. Bell ringers appear to be a useful tool to engage students in science learning as well as to teach them critical thinking skills and being stewards of the environment. I also wonder what it means to be a good steward of the environment and the role as a science teacher especially in an inner city school in fostering environmental stewardship. I wonder do my students care about being good stewards of the environment. Another question I wonder about is whether stories make science more relatable to students and make them wonder more. Next year I plan to continue to use bell ringers daily and will probably try to find more opportunities for my students to collect data and to review science content through bell ringers. Science is a way of thinking and as we provide students with opportunities to see how science is real in their daily lives is key to helping them become lifelong learners. Bell ringers are easily implemented in class, show student misconceptions, and engage

students in making science real to them which is a win for both the teacher and the students.

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APPENDICES

APPENDIX A
INSTITUTIONAL REVIEW BOARD EXEMPTION



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INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

MEMORANDUM

TO: Alison Montemurro and Marcie Reuer
FROM: Mark Quinn *Mark Quinn*
Chair, Institutional Review Board for the Protection of Human Subjects
DATE: November 27, 2017

RE: "Increasing Interest in Learning Through Engaging "Bell Ringers" [AM112717-EX]

The above research, described in your submission of November 27, 2017, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

- X (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
- X (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.
- (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
- (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.
- (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.
- (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

APPENDIX B
LIKERT SURVEY

Student attitude Survey: The following questions are for research purposes only and in no way are reflected in your grade. Please do your best to answer the questions honestly. Choose a rating 1-5 for each statement (1-Never to 5-Always).

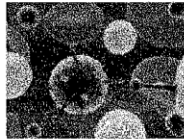
Statements	Never 1	Rarely 2	Sometimes 3	Often 4	Always 5
1. I think what I am learning at school is interesting.					
2. I enjoy learning new things in class.					
3. I think learning is boring.					
4. I like my school.					
5. In class, I work as hard as I can.					
6. When I am in class, I participate in class activities.					
7. I pay attention in class.					
8. When I am in class, I act like I am working.					
9. In school I do just enough to get by.					
10. When learning things for school, I try to see how they fit together with things I already know.					

Adapted from The Student Engagement in Schools Questionnaire (SESQ) and the Teacher Engagement Report Form-New (TERF-N): Examining the Preliminary Evidence published in Contemporary School Psychology 2011, Vol. 15

APPENDIX C
BELL RINGERS USED



Is That Thing Alive or What?



Four biology students were discussing whether some objects set out by their teacher were alive or not. The objects included a sunflower seed, a lizard, some bread mold, a houseplant, and a microscope with a slide of bacteria from some yogurt. Here are their thoughts about which items were alive:



Susie: "Only the lizard and the houseplant are alive."

Sam: "I agree with Susie – the lizard and houseplant are alive – and I also think the sunflower seed is alive too."

Carl: "I disagree with both Susie and Sam. I think all five objects are alive."

Natasha: "I think that all of them are alive except the bacteria – there can't be living bacteria in yogurt that we eat. That would be gross!"

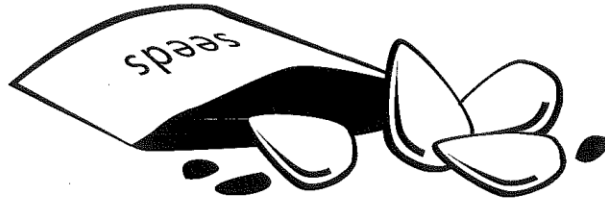
Which biology student do you most agree with?

What rule or rules do think the student you chose is using to classify something as alive?

Needs of Seeds

Seeds sprout and eventually grow into young plants called seedlings. Put an X next to the things you think a seed needs in order for it to sprout.

- ☐ water
- ☐ soil
- ☐ air
- ☐ food
- ☐ sunlight
- ☐ darkness
- ☐ warmth
- ☐ Earth's gravity
- ☐ fertilizer

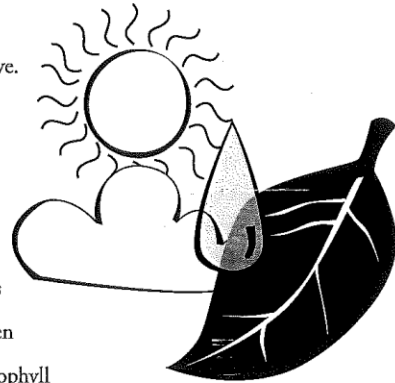


Explain your thinking. Describe the "rule" or reasoning you used to decide what a seed needs in order to sprout.

Is It Food for Plants?

Organisms, including plants, need food to survive.
Put an X next to the things you think plants
use as food.

- | | |
|---|--------------------------------------|
| ☐ sunlight | ☐ soil |
| ☐ plant food from a garden store | ☐ water |
| ☐ sugar | ☐ leaves |
| ☐ carbon dioxide | ☐ oxygen |
| ☐ minerals | ☐ chlorophyll |
| ☐ fertilizer | ☐ vitamins |



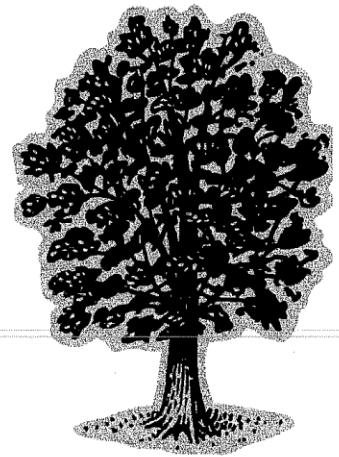
Explain your thinking. How did you decide if something on the list is food
for plants?



The Mighty Oak

An acorn, the seed of an oak tree, has a dry mass of only a few grams. Under favorable conditions the acorn will sprout into a sapling and grow to be a mature oak tree with a dry mass 1 ton or more. Which of the following contributes most directly to this huge increase in mass?

- A. The roots absorb minerals from the soil.
- B. The leaves absorb CO_2 gas from the atmosphere.
- C. The roots absorb water from the soil.
- D. Light from the sun is absorbed into the leaves.



Please indicate the letter of the choice you think contributes most directly to the increase in mass as the acorn grows into a tree.

Explain your reasoning for selecting the choice you did and not selecting the other choices.

Seed Germination Lab

Germination: a series of events that results in the growth of a plant from a seed.

Problem: How long does it take a _____ seed to germinate?

Hypothesis: _____

Materials:

- seeds
- small amount of potting soil
- 1 microcentrifuge tubes
- eye dropper
- 75 cm pieces of string
- meter stick
- water
- sharpie marker

Procedure:

1. Obtain a micro-centrifuge tubes
2. Using a Sharpie marker, label each tube with your initials, class period, and date you began the experiment on the tubes.
3. Place a very small pinch of potting soil into each of the tubes.
4. Place a radish seed into tube and cover with a small amount of soil.
5. Add 2 drops of water to each tube.
7. Cap the tube.
8. Thread a piece of string through the cap of tube and tie ends tightly.
9. You will WEAR (yes!! You read that correctly!) your experiment for the next 5 days (outside clothing) and make observations each day as your new "pet" seed germinates.
10. Obtain data daily for the next 5 days. You must remember to wear your tubes! Each day that you wear your plant to class is worth 5 points of your final grade. Your careful observations will bet the remainder of the grade. Use the data table on the following page. If you are caught neglecting your pet plant during the day, expect to lose your points!

Day #	Observations (size, color BE SPECIFIC AND PRECISE!!) ***"nothing" is not an acceptable piece of data	5 pts. for TLC
Day 1		
Day 2		
Day 3		
Day 4		
Day 5		

Data Analysis (explain in words what your data shows):

Conclusion:

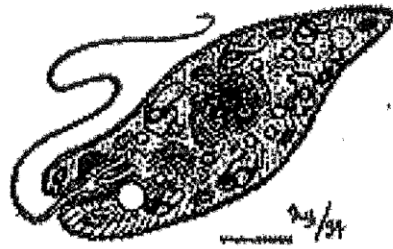
A. Evaluation of Hypothesis:

B. Questions for Further Study:

1. _____

2. _____

3. _____



Eureka! It's Alive!

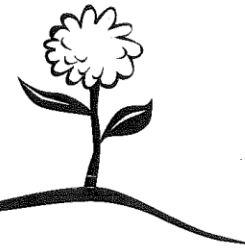
A scientist discovers a new unicellular organism. Which items listed below might the scientist be able to study within the new organism to better understand the organism's structure and function?

- | | | |
|--|------------------------------------|---------------------------------------|
| ☐ heart | ☐ atoms | ☐ chloroplast |
| ☐ carbohydrates | ☐ nucleus | ☐ enzymes |
| ☐ mitochondria | ☐ lipids | ☐ DNA |
| ☐ lung cells | ☐ ribosomes | ☐ molecules |
| ☐ muscle tissue | ☐ protein | ☐ chromosome |
| ☐ intestines | ☐ vacuole | ☐ brain tissue |

Explain your reasoning for excluding certain items on the list and including others.

Is It a Plant?

Each of the things listed below can be found living and growing in its environment. Put an X next to the things that you consider to be plants.



- | | | |
|----------------------------------|--------------------------------------|-----------------------------------|
| ☐ fern | ☐ grass | ☐ moss |
| ☐ vine | ☐ grasshopper | ☐ tomato |
| ☐ mold | ☐ flower | ☐ tree |
| ☐ onion | ☐ weed | ☐ bush |
| ☐ cactus | ☐ bacteria | ☐ mushroom |
| ☐ cabbage | ☐ dandelion | ☐ carrot |

Explain your thinking. Describe the "rule" or reasoning you used to decide if something is a plant.

[illegible][illegible]

to his boot to blind temporarily an entire nest of his mates. Its odor is to be disguised with other gases. The Germans sometimes chose to mix mustard with xylol bromide, a tear gas that smells like lilac, and so pass in the wartime spring that men ran in terror from a breeze with blossoming lilac shrubs.

are not nearly all the gases and poisons developed in the poisonous laboratory of the Great War. There were sneezing gases and



A "Grape" Question

Six friends were sharing a bowl of grapes. Eric asked, "How could glucose from a grape provide energy to your muscle cells to move your fingers to pick up more grapes?" The following are answers Eric's friends gave in response to his question:

Billy: "The glucose is digested into simpler molecules having more energy."

Shannon: "The glucose reacts to become other molecules."

Tyler: "The glucose is turned into energy."

Hannah: "The energy of the glucose is transferred to other molecules."

Jessica: "The energy of the glucose is transferred to carbon dioxide and water."



Which of Eric's friends do you agree with most? Explain the reasoning for your choice.

Biology: Structure (Form) and Function

Name _____

-
1. What does structure and function mean in Biology?

Watch: https://www.ted.com/talks/michael_dickinson_how_a_fly_flies

2. What is significant about the structure of a fly and its wings? Describe three things about the fly and its wings.
3. Choose a microscope slide
4. Write down the label on the slide

-
5. Research what is on your slide. Research by searching with two different search phrases.

Write your search phrases here:

1)

2)

6. What is the function of the organism or part of an organism that is on the slide?

Describe the function from a large scale (macroscopically)

Describe the function of that part of an organism (microscopically)

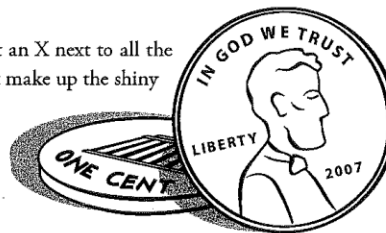
7. List three sources you used for information

8. Make a poster with your information:

Make a drawing of your structure and a detailed description of the functions of your structure (on the front)-Don't forget both macroscopically (large scale) and microscopically (small scale)

Write the search phrases and websites (on the back)

A shiny new penny is made up of atoms. Put an X next to all the things on the list that describe the atoms that make up the shiny new penny.



- ☐ hard ☐ soft
☐ solid ☐ copper-colored
☐ very small ☐ has mass
☐ always moving ☐ do not move ☐ cold
☐ warm ☐ shiny ☐ dull
☐ made of smaller particles
☐ contains mostly empty space

Describe your thinking about the atoms that make up the penny. Explain why you selected the things on the list as ways to describe atoms.

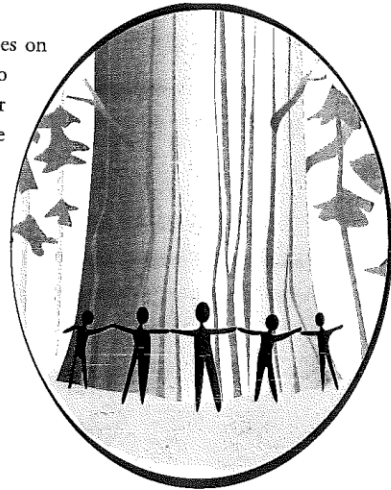
[illegible]

Giant Sequoia Tree

The giant sequoia tree is one of the largest trees on earth. It starts as a small seedling and grows into an enormous tree. Five children can stretch their arms across the width of the trunk of one of the large sequoia trees!

Where did most of the matter that makes up the wood and leaves of this huge tree originally come from? Circle the best answer.

- A** sunlight
- B** water
- C** soil
- D** carbon dioxide
- E** oxygen
- F** minerals
- G** chlorophyll



Explain your thinking. How did you decide where most of the matter that makes up this tree came from?

TALES FROM THE FIELD

SHOCKING SCIENCE

don't fry
this at homeKEN CATANIA, PROFESSOR OF
NEUROBIOLOGY AT VANDERBILT UNIVERSITY

⇒ In 2014, I set out to write a book about predator nervous systems. I got some electric eels to observe and photograph for a chapter about electrogenic fish. I could have just read existing studies on the animals and their behavior, but I wanted to get to know them for myself.

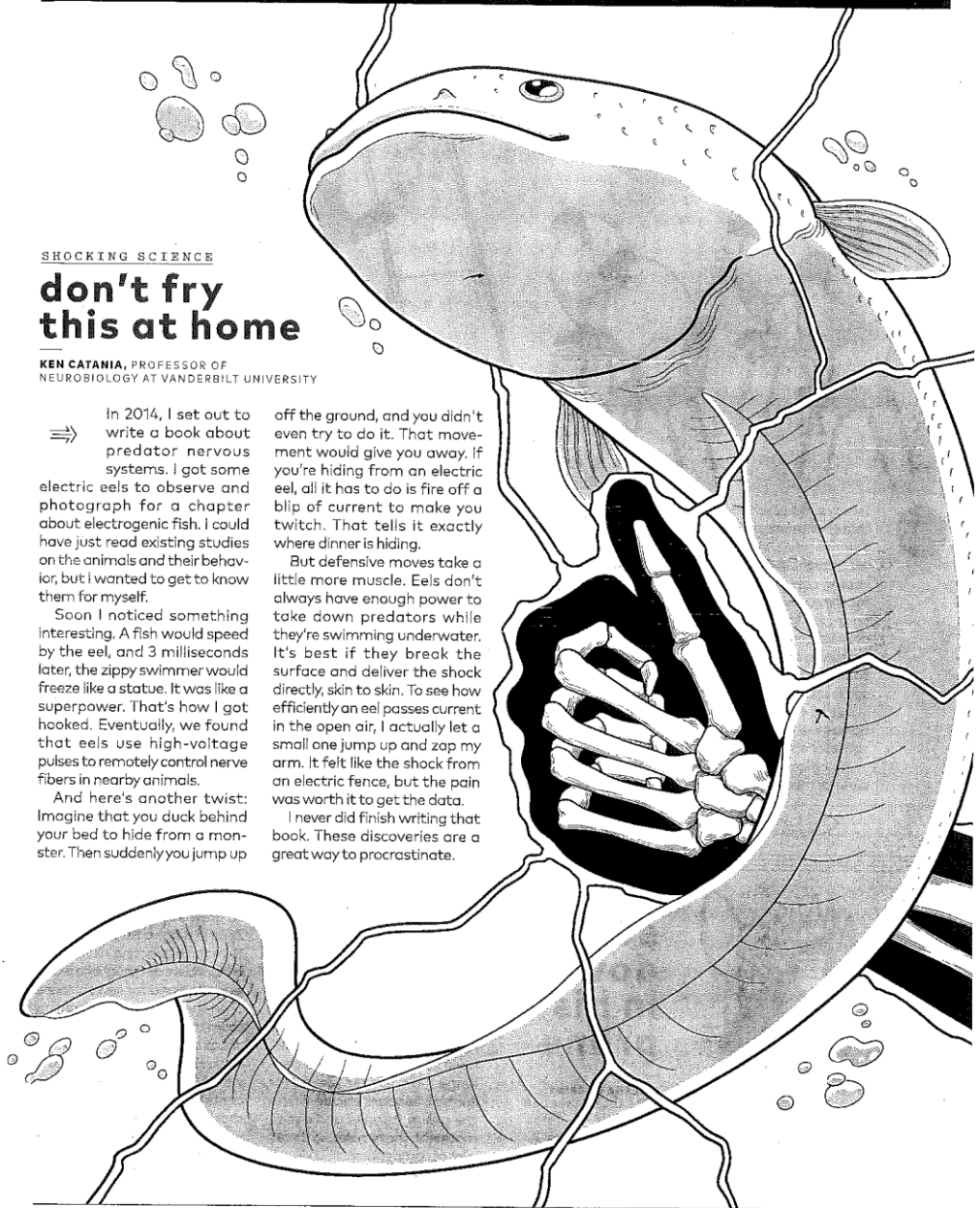
Soon I noticed something interesting. A fish would speed by the eel, and 3 milliseconds later, the zippy swimmer would freeze like a statue. It was like a superpower. That's how I got hooked. Eventually, we found that eels use high-voltage pulses to remotely control nerve fibers in nearby animals.

And here's another twist: Imagine that you duck behind your bed to hide from a monster. Then suddenly you jump up

off the ground, and you didn't even try to do it. That movement would give you away. If you're hiding from an electric eel, all it has to do is fire off a blip of current to make you twitch. That tells it exactly where dinner is hiding.

But defensive moves take a little more muscle. Eels don't always have enough power to take down predators while they're swimming underwater. It's best if they break the surface and deliver the shock directly, skin to skin. To see how efficiently an eel passes current in the open air, I actually let a small one jump up and zap my arm. It felt like the shock from an electric fence, but the pain was worth it to get the data.

I never did finish writing that book. These discoveries are a great way to procrastinate.



as told to Ellen Airhart / illustration by Anuj Shrethra

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APPENDIX D
PHOTOS OF STUDENTS IN BLOCKS 3 AND 5 AND
EXAMPLES OF THEIR WORK



