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The inclusion of engineering design into the high school biology curriculum

Cody D. LaKose
University of Northern Iowa

Abstract
The purpose of this project is to develop engineering-based lessons for a life science course,i.e. biology, in order to meet the NGSS standards as well as increase student interest in engineering by incorporating the principles of engineering design into the traditional science classroom.

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Chapter 1 Introduction

Various reform movements for science education have been introduced in the past century (Collins & Pea, 2008; DeBoer, 1991). The current science education movement includes the incorporation of the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). There is a national call to educate our youth on the principles of science, technology, engineering, and mathematics (STEM), which our current education system is lacking (National Research Council, 2012). Largely influenced by The National Research Council's *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (2012), the NGSS includes a large emphasis on integrating engineering design practices into the K-12 science curriculum. According to the National Research Council (2012), in order to produce students capable of entering a career related to science, engineering, or technology, a need exists to focus on educating students with the fundamental knowledge of these subjects.

Science education reform movements have had different focuses and intentions, but increasing student achievement, engagement, and interest in the sciences have been primary components of every science education reform movement to date (Collins & Pea, 2008; DeBoer, 1991). There is much educational literature focusing on student interest in K-12 science courses (Bybee & McCrae, 2011; Krapp & Prenzel, 2011; Olsen, Prenzel, & Martin, 2011; Osborne, 2003). Bybee & McCrae (2011) state that students are primarily interested in topics that they might encounter personally (i.e. health and safety), while they are less interested in learning about how research is conducted as well as explanations of scientific phenomena. Although several variables are suggested to explain what influences student interest, current research is left without any consensus (Bybee & McCrae, 2011; Krapp & Prenzel, 2011). Furthermore, Osborne (2003) states:

> The increasing attention to the topic is driven by a recognition that all is not well with school science and far too many pupils are alienated by a discipline that has increasing significance in contemporary life, both at a personal and a societal level. While the body of research conducted has been good at identifying the problem, it has had little to say definitively about how the problem might be remediated (p. 1073).

Alleviating the issues surrounding student interest in STEM is an ongoing battle. Krapp & Prenzel (2011) acknowledge the difficulty for schools to increase student interest in science and technology, but explicitly state it is the task of the schools to make students aware of the importance of these subject areas. One such approach centers on increasing the relevance of science to students' everyday lives, such as connecting personal or societal concerns requiring technological or scientific knowledge (NGSS Lead States, 2013). The implementation of engineering design practices into the science curriculum may help increase student interest in the sciences (Daugherty, 2012).

The enactment of STEM into our educational system, particularly the engineering component, is a work in progress (Brophy, Klein, Portsmore, & Rogers, 2008; Katehi, Pearson, & Feder, 2009). Engineering based curricula have been introduced at lower educational levels, such as *Engineering is Elementary* (*EiE*) (Cunningham, 2009). Successful engineering-specific curricula have also been implemented at the secondary level, such as *Project Lead the Way* (*PLTW*) and *Adventure Engineering* (Brophy, Klein, Portsmore, & Rogers, 2008). However, there is no literature available as to the incorporation and effects of engineering practices directly into high school life science courses, such as biology.

Schools using *EiE* engineering curricular units have shown improvement of student attitudes to both science and engineering (Lachapelle, Phadnis, Jocz, & Cunningham, 2012). Furthermore, *EiE* students have consistently shown improvements on post-assessments of science and engineering concepts (Cunningham & Lachapelle, 2007). However, as previously mentioned, the engineering curricular units currently available at the secondary level tend to be separated from traditional science courses, such as the aforementioned *PLTW* (Brophy, Klein, Portsmore, & Rogers, 2008). The purpose of this project is to develop engineering-based lessons for a life science course, i.e. biology, in order to meet the NGSS standards as well as increase student interest in engineering by incorporating the principles of engineering design into the traditional science classroom.

Chapter 2 Literature Review

Theoretical Framework

Constructivism, although not without its critics, has been defined as a proper philosophical way of learning science (Gil-Pérez et al., 2002; Matthews, 1997; Staver, 1998). Furthermore, constructivist principles are applicable to learning in an engineering environment (Fowler, McGill, Armarego, & Allen, 2002). As stated by the NGSS (2013), all students need opportunities to engage in engineering activities and concepts along with the methods and concepts of science. Moreover, the NGSS seeks to raise engineering design to the same level of scientific inquiry at all levels, K-12 (NGSS Lead States, 2013). An assumption is made in this project that constructivism is a proper means to guide science instruction and is congruent with engineering practices, as evidenced by the integration of engineering into the science curriculum with the NGSS.

The definition of constructivism pertains to knowledge being actively constructed by the learner, with knowledge acting as the meaningful interpretation of experiences from reality (Bodner, 2004; Cobern, 1995). According to Cobern (1995), constructivism is a model to describe learning which includes:

1. The student is always active when learning takes place.
2. This active process is the process of making sense. Learning does not occur by transmission but by interpretation.
3. Interpretation is always influenced by prior knowledge.
4. Interpretation is facilitated by instructional methods that allow for the negation of ideas. (p. 12).

Furthermore, inquiry-teaching methods are based upon constructivist philosophy: "Inquiry activities are powerful specifically when they promote discourse...by the same reasoning, cookbook labs and demonstrations are far less effective" (Cobern, 1995, p. 12). Developing engineering based activities for the life sciences will be consistent with an inquiry-based approach for teaching, or a constructivist's mode of learning.

According to Matthews (1997), constructivism can mean a variety of things to various researchers, and therefore can be problematic; stating, "constructivism, in all its varieties, has been the subject of heated debate" (p. 5). However, Matthews goes on to recognize the importance of the constructivist view in science education including views about "epistemology, teaching, curriculum, educational theory, ethics, ontology, and metaphysics" (p. 6).

Gil-Pérez et al. (2002) corroborate Matthews's views, speaking about the difficulties in defining constructivism as well as its many critics. However, Gil-Pérez et al. recognize constructivism as a valid theory to explain learning science practices. According to Staver (1998), regardless of what "brands of constructivism" are used (i.e. radical or social constructivism), "constructivism is sound theory with which to explain the practice of science pedagogy" (p. 502-503).

The assumption is that learning is a complex process and that "knowledge is internally constructed by the learner…but acknowledges that learning involves making meaning of experiences and therefore the process of construction of knowledge by the learner is unique" (Fowler, McGill, Armarego, & Allen, 2002, p. 10). Fowler et al. (2002) recognize that a constructivist approach is compatible to learning in an engineering environment, and best serves students to become life-long learners.

Albeit not directly related to engineering design instruction, problem-based learning and project-based learning (PBL) have been identified as constructivist pedagogical approaches (Ferreira & Trudel, 2012; Thomas, 2000). Engineering design principles revolve around solving a problem, which is congruent with problem-based learning. Centered in this project is the assumption that engineering design instruction is consistent with a constructivist pedagogical approach.

Science Reform History and Current Status

George DeBoer (1991) wrote a comprehensive history of scientific reform movements in *A History of Ideas in Science Education: Implication for Practice*. This included the origins of classical studies pre-1900, the Committee of Ten and the Committee of College-Entrance Requirements commitment to including science in the curriculum, the Progressive Era (1917-1957) leading to renewed focus on the philosophy of teaching, *Sputnik* and its equation for success, and finally scientific literacy and the new progressivism in the 1980's stating that all students should have a broad and functional understanding of science. Collins & Pea (2008) echoed DeBoer, beginning with the curricular reform movement sparked by *Sputnik*. They also speak about the cognitive science movement (scientific literacy), the standards movement beginning with *A Nation at Risk* (1980), and the systemic approach to coherence in science learning.

Science literacy was the underlying focus beginning in the 1990's with the American Association for the Advancement of Science's (AAAS) *Science For All Americans* (1990). The aim of this release was to increase science literacy for all Americans. A scientifically literate person was defined as:

> One who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes (p. xvii).

The AAAS (1993) strengthened these thoughts, and released *Benchmarks For Science Literacy*. This was a comprehensive document of statements of what all students should know and be able to do in science by the end of grades 2, 5, 8, and 12. Instead of being viewed as a curriculum, the benchmarks were a tool that could be organized however state or local efforts chose. It was meant as a companion to the *Science For All Americans* release, all in the aim to increase science literacy for all Americans.

The National Research Council (NRC) (1996) further expanded on the necessity of scientific literacy with the release of the *National Science Education Standards*. Specifically, the standards "outline what students need to know, understand, and be able to do to be scientifically literate at different grade levels" (p. 2). Maintaining the ideas within *Science For All Americans*, the "*Standards* apply to all students, regardless of age, gender, cultural or ethnic background, disabilities, aspirations, or interest and motivation in science…but all students can develop the knowledge and skills" (p. 2).

The NRC's *Standards* were covered in six chapters:

- Standards for science teaching (Chapter 3).

- Standards for professional development for teachers of science (Chapter 4).
- Standards for assessment in science education (Chapter 5).
- Standards for science content (Chapter 6).
- Standards for science education programs (Chapter 7).
- Standards for science education systems (Chapter 8).

The NRC stated that all six chapters should be covered to achieve the vision of science education set forth by the *Standards*. For teachers, Chapter 6 is the most relevant chapter, speaking directly to the content that needs to be delivered:

- Unifying concepts and processes in science.
- Science as inquiry.
- Physical science.
- Life science.
- Earth and space science.
- Science and technology.
- Science in personal and social perspective.
- History and nature of science.

According to the NRC, the “first category is presented for all grade levels…(and) the other seven categories are clustered for grade levels K-4, 5-8, and 9-12” (p. 6). While inquiry and technology were points of emphasis in these standards, the advent of engineering practices was unseen. It was not until the next set of standards that these practices were brought to the forefront.

The NRC released *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* in 2012. This was a comprehensive document that began a process to create new standards for K-12 science education, in essence updating the *Standards* first released in 1996. While taking all previous contributions to science education into consideration, acknowledgement was made that science and education has progressed, and a revision of the standards was necessary.

The NRC determined that science education should be built around three primary dimensions. These are scientific and engineering practices, crosscutting concepts that unify engineering and science, and four primary science disciplines: (1) physical sciences, (2) life sciences, (3) earth and space sciences, and (4) engineering, technology, and applications of science. The framework sets a precedent to keep up with the national focus of science, engineering, and technology that pervade our modern society, while maintaining meaningful learning for all students (NRC, 2012).

The *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) are the next step in the process initiated from *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. It began by states developing K-12 science standards arranged in a coherent manner across grades and disciplines. The intent of the NGSS was to prepare internationally benchmarked standards for students, preparing them for college and careers, with special attention to the need surrounding science, technology, and engineering. The NGSS underwent multiple reviews, including two public drafts, in an attempt to produce a set of high quality, K-12 science standards ready for state adoption. The NGSS were completed and published on their website in April 2013, although they have yet to be mandated by most states, including Iowa.

At the high school level, the NGSS recognizes four specific standards under the domain of *Engineering Design*:

> HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
>
> HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
>
> HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as wells as possible social, cultural, and environmental impacts.
>
> HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Furthermore, the NGSS identifies that in the life sciences, high school students are expected to design, evaluate, and refine solutions within some of the life science specific performance expectations. All four previously mentioned HS-ETS1 performance expectations are to be completed by 12th grade. Specifically, the essential skills brought forth by the NRC (2013) include quantifying criteria and constraints, breaking down complex problems into smaller and more manageable problems, finding alternative solutions by evaluating criteria and trade-offs, as well as using computer simulations to model the impact of proposals.

These performance expectations are drawn from literature by the NRC on how students learn, which "include young children's capacity to learn, a focus on core ideas, and development of true understanding over time, the consideration both of knowledge and practice, the linkage of science education to students' interests and experiences, and the promotion of equity" (NRC, 2012, p. 24). It is evident that constructivist ideals are embedded within the *Framework*, which were inspired by all the previous works mentioned above, that ultimately lead to the NGSS:

> Thus, before they even enter school, children have developed their own ideas about the physical, biological, and social worlds and how they work. By listening to and taking these ideas seriously, educators can build on what children already know and can do. Such initial ideas may be more or less cohesive and sometimes may be incorrect. However, some of children's early intuitions about the world can be used as a foundation to build remarkable understanding, even in the earliest grades. Indeed, both building on and refining prior conceptions (which can include misconceptions) are important in teaching science at any grade level (p. 24-25).

The implementation of the standards suggested by the NGSS is a fairly daunting challenge. Teachers' focus should include promoting science literacy for all students, covering all standards by the 12^{th} grade, including new engineering design standards, as well as a continued focus on inquiry and technology. The current impetus of the NGSS includes incorporating engineering design practices that are interwoven in all science disciplines, including life science. While engineering design standards can easily be done in separate industrial technology courses, or smoothly integrated into a physics course, it can be a challenge to incorporate engineering design principles into life science courses such as biology (to be explained below). The major point of this project is to alleviate this dilemma, and bridge the gap in the literature.

Engineering and Science Education

While the application of STEM (specifically engineering) practices in K-12 science education have been recommended, the process of restructuring our educational system is a work in progress. According to Katehi, Pearson & Feder (2009), efforts to "improve STEM education have focused on mathematics and science, but an increasing number of states and school districts have been adding technology education to the mix, and a smaller but significant number have added engineering" (p. 6). There remains an incredible amount of potential as to what engineering practices can contribute to K-12 education, but "pursuing the goal of STEM literacy in K-12 schools will require a paradigm shift for students, teachers, administrators, textbook publishers, and policy makers, as well as the many scientists, technologists, engineers, and mathematicians involved" (p. 10). Incorporating STEM into the science curriculum, particularly engineering, is in the infancy stages. There are little to no activities developed for incorporating engineering in the life sciences, a major focus of this project.

One effort to incorporate engineering in the science curriculum, including life science, is *Engineering is Elementary* (*EiE*). *EiE* was initiated in 2003 as a means to "take advantage of the natural curiosity of *all* children to cultivate their understanding and problem-solving in engineering and technology" (Cunningham, 2009, p. 12). This was a direct result of the findings that few Americans were technologically literate and knew little about engineering. *EiE* was a collaborative effort between teachers and engineers to create a "research-based, standards-driven, classroom-tested curriculum that integrates engineering and technology concepts and skills and elementary science topics and mathematics learning, as well as literacy and social studies" (p. 11-12). At its core, *EiE* has four main goals:

1. Increase children's technological literacy.
2. Improve elementary educators' ability to teach engineering and technology.
3. Increase the number of schools in the United States that include engineering in their curricula.
4. Conduct research and assessments to further the first three goals and to develop a knowledge base on the teaching and learning of engineering at the elementary level.

EiE has shown that schools that have adopted their curricular units have improved student attitudes in both science and engineering and has shown improvement in student achievement on post-assessments of science and engineering concepts (Cunningham & Lachapelle, 2007; Lachapelle, Phadnis, Jocz, & Cunningham, 2012).

There are few secondary engineering programs, such as *Project Lead the Way* (*PLTW*), *Adventure Engineering, The Infinity Project*, and the *Vanderbilt Instruction of Biomedical Engineering for Secondary Science* (*VIBES*), although none of these programs focus specifically on the life sciences (Brophy, Klein, Portman, & Rogers, 2008).

Furthermore, these established programs tend to exist outside the realm of traditional science courses as solitary engineering based units. For example, *PTLW* is usually offered as a separate program, most often under industrial technology designations. There appears to be minimal research of the implementation of crosscutting concepts that unify engineering and science in traditional high school science courses, such as biology, as recommended by the NGSS.

The NGSS (Appendix I) are committed to integrating engineering design "at all levels, from kindergarten to grade 12" (NGSS Lead States, 2013, p. 1). The underlying assumption is that "providing students a foundation in engineering design allows them to better engage in and aspire to solve the major societal and environmental challenges they will face in the decades ahead" (NGSS Lead States, 2013, p. 1). Furthermore, the NGSS (Appendix I) state:

> Engineering design at the high school level engages students in complex problems that include issues of social and global significance. Such problems need to be broken down into simpler problems to be tackled one at a time. Students are also expected to quantify criteria and constraints so that it will be possible to use quantitative methods to compare the potential of different solutions. While creativity in solving problems is valued, emphasis is on identifying the best solution to a problem, which often involves how others have solved it before. Students are expected to use mathematics and/or computer simulations to test solutions under different conditions, prioritize criteria, consider trade-offs, and assess social and environmental impacts (p. 5).

The looming question that remains is: How do engineering practices fit within the life sciences? No groundwork has been done in this specific area, which is what this project aims to answer. Namely, at the culmination of this project will be tailor-made, classroom ready engineering activities for the life sciences that can be used by teachers in the field.

Student Interest in Science Education

A focus on student interest in science dates back to the early 1800's, with Johann Friedrich Herbart, while the concept of interest in the general educational setting dates back as far as the 1700's with Jean Jacques Rousseau (Krapp & Prenzel, 2011). Stalwarts of science education, such as John Dewey, also provided further research based on Herbart's ideas. Krapp & Prenzel (2011) state "interest must not only be regarded as a desirable motivational condition of learning but also as an important goal or outcome of education" (p. 29). Over the years, various approaches have been used to study the effect of interest in science (i.e. attention, curiosity, intrinsic motivation, etc.), with recognition that interest is a central tenant in science education. Furthermore, it is the role of schools to promote science and technology as visible and available as a means to increase interest in these areas. While not being an easy task to decipher, nor having universal consent as to what dictates it, student interest in science remains a hot topic in education (Krapp & Prenzel, 2011).

The Programme for International Student Assessment (PISA) was an effort to provide further research on the topic of student interest in science education (Olsen, Prenzel & Martin, 2011). With science as the domain focus in the 2006 survey, PISA surveyed 57 countries on both student knowledge and attitudes towards science. Bybee & McCrae (2011) found that within nearly all countries, general interest in science by students was positively related to their performance. Furthermore, they found that students were most interested in learning about topics that were personally relevant to them, with human biology the broad area of science that scored the most interest.

Osborne (2003) found similar findings to that of the PISA study. Specifically, it is inherent that students have “task value,” which Osborne (2011) defined as “the degree to which an individual believes that a particular task is able to fulfill personal needs or goals” (p. 1074). Student interest is a key component of task value, and it is vital that further research be done to see which factors increase student interest. According to Osborne (2003), regarding the problem of generating student interest, “the body of research conducted has been good at identifying a problem, it has had little to say definitively about how the problem might be remediated” (p. 1073). One suggestion is that good teaching should require situational interest and engagement.

EiE’s teachers and researchers have conducted research, specifically in the areas of the impact of engineering on student attitudes, interest, and achievement in science (Cunningham & Lachapelle, 2007; Lachapelle, Phadnis, Jocz, & Cunningham, 2012). Cunningham & Lachapelle (2009) analyzed quantitative data between pre- and post-assessments on a specific unit on water. They found that *EiE* students consistently showed improvements on post-assessments designed to assess student understandings of both engineering and science concepts. When the ability to compare to a control group was available, *EiE* students tended to perform significantly better than control students.

Lachapelle, Phadnis, Jocz, & Cunningham (2012) designed a survey utilizing Likert scales to determine each student’s attitudes towards a series of statements. The survey intended to measure students' interest in scientific and engineering skills and jobs as well as some of their attitudes towards science, math, scientists, and engineers. The research revealed that students participating in *EiE* showed positive changes in their attitudes towards engineering and science, performed significantly better on assessments of science and engineering content, and positively affected students' interest in engineering careers.

In order for sound instruction to take place within a classroom, student interest is a variable that needs to be considered (Krapp & Prenzel, 2011). Engineering practices could serve this need, as identified by problem-based learning literature. According to Ferreira & Trudel (2012), students "enjoyed and benefited from," "emerged as active learners," "were more motivated to learn," and had a "sense of ownership and control of their learning" as a result of problem-based learning (p. 28). Considering that engineering design could be considered on par with PBL, these ideas are consistent with the literature above as well as the foundation of the NGSS, including engineering as a potential means to remedy the issues of student apathy.

Incorporating engineering into the science curriculum is a novel idea set forth by the NGSS. There are little to no resources available on the merging of engineering design practices into life science courses, particularly biology. This project begins to address these issues. Upon completion of this project there will be at least five life science engineering related lessons created, modified, or adapted to align with the NGSS. These activities will be shared so that common teachers have resources readily available to implement into their classrooms.

Chapter 3 Project

Life science courses, in particular biology, may be diverse in their curriculum designs. Common units include the nature of science, cells, genetics, evolution, ecology, biodiversity, and human biology over the course of one year. The timeline followed for this project includes the nature of science, microscopy, cells, genetics, evolution, and biodiversity, consistent with the local curriculum of Central Community Schools. The order of activities for this project are: *Toxic Popcorn*, *What is "Nanoscale"/ "Nanotechnology"?*, *Effects on the Rate of Photosynthesis in Elodea*, *Design a Virus*, and *Biomimicry: Nature's Design*. While these activities may be followed in a differing sequence dependent upon the timeline of your biology curriculum, the order was designed to accommodate Central Community School's life science curriculum.

Nature of Science

- *Toxic Popcorn* – An activity that introduces the steps of the engineering design process, which is what engineers use to solve problems. Working in teams, students solve a challenge presented to them by designing a product and process to safely remove "toxic" popcorn from their city (see Appendix for complete student handout and teacher notes).

Toxic Popcorn is intended for use early in the school year, possibly in the first few days of class. This activity can be served as an icebreaker activity, forcing students to work together for a common goal. Slightly modified from *Toxic Popcorn Design Challenge* (IEEE, n.d.) and *Toxic Popcorn* (Boesdorfer, 2013), which contains no biology related standards, it acts as an introduction to the steps of the engineering design process. Furthermore, upon completion of the activity, a conversation is had comparing and contrasting the engineering design process to the scientific method. To summarize, this activity serves as a beginning of the year introductory/ice-breaker lesson, getting students readjusted to the nature of science while introducing the engineering design process.

Microscopy

- *What is "Nanoscale"/ "Nanotechnology"?* – An activity that explores nanotechnology and how engineers have learned to explore the world at the nanoscale in order to understand exactly how small the nanoscale is, how surface area changes at the nanoscale, and to work in teams to develop potential applications of nanotechnology (see Appendix for complete student handout and teacher notes).

This activity serves as a precursor to cell biology, including the topic of surface area, which is an important concept to cellular structure and function (i.e. surface area to volume ratio). When introducing light microscopy techniques, a review of the metric system and scaling is important. While students generally have prior exposure to light microscopes, they have limited to zero knowledge of more powerful microscopes, such as the electron microscope. While compound light microscopes are used extensively in biology courses, they are limited to 1,000-2,000X magnifications. While this is still a useful tool for high school biology laboratories and inquiry investigations, several concepts would yet to be discovered if it was not for the electron microscopes (i.e. cell organelles, viruses, etc.). A large amount of the content covered in life science was acquired with the aid of electron microscopes, a fact that is often overlooked by biology students.

This activity was modified from *Exploring at the Nanoscale* (IEEE, n.d.) and gives students further insight into the scanning electron microscope and how it operates, the metric system and the topic of scaling, as well as an opportunity to review the engineering design process by brainstorming an application of nanotechnology. The unit occurs early in the curriculum of Central Community Schools, following the nature of science and preceding cells.

Surface area to volume ratio is a critical concept within cellular structures and functions, a topic introduced in this activity that will aid in their understandings of the standards covered in the cell unit. This activity will serve as students' second exposure to the engineering design process, and considering their limited exposure up to this point, it also serves as a re-introduction to the steps of the engineering design process. Students gain insight into engineering related careers and investigate applications of how engineers are often provided with a problem and seek to solve it.

Cells

- *Effects on the Rate of Photosynthesis in Elodea* – Using an initial apparatus that is set up for them, students focus on the optimization step of the engineering design process. By controlling and manipulating different variables, students are tasked to maximize the rate of photosynthesis of the aquatic *Elodea* plant (see Appendix for complete student handout and teacher notes).

This activity focuses primarily on the optimization or improve step of the engineering design process. It is intended for use upon completion of cells and their processes, specifically cellular respiration and photosynthesis. A good activity for students to observe the specific products of photosynthesis, namely oxygen bubbles, bringing the written chemical equation to life. This activity also serves as a review of the nature of science, as students are controlling and manipulating variables in this design.

This activity borrows an apparatus from *Investigating the Rates of Photosynthesis* (Biology Corner, n.d.) and a scenario concocted in *Crush a Can for CanCo* (Boesdorfer, 2013). Students are actively involved with improving, or optimizing the apparatus in hopes to increase the rate of photosynthesis in *Elodea*. Having been previously introduced to the steps of the engineering design process, students are focused on a specific component of this process, giving them a specific example of how some engineers operate in the real world. An engineering activity does not need to touch upon every aspect of the engineering design process, and this serves as an example of that while also covering a plethora of life science standards (NGSS Lead States, 2013).

Evolution

- *Design a Virus* – Using their knowledge of viral pathogens, students are tasked with designing the world's deadliest virus as a means to threaten opposing nations against global war (see Appendix for complete student handout and teacher notes).

Design a Virus is an activity that serves as a review of cell structure and function. In order for a virus to attack a cell, it needs to gain entry within the cell so it can highjack its machinery and replicate more viruses. In the natural environment, there is often an arms race between various organisms, where a change in one organism's structure will result in the change of the corresponding structure of the other organism or virus (viruses are non-living). In essence, this is how individuals can get the flu or common cold multiple times throughout the course of their lifetime. In this case, students are tasked with creating a virus that is optimal for attacking specific cell types.

While not evolution by means of natural selection, students are able to research successful modifications of various real-life pathogens that have evolved naturally in order to engineer their specific virus. Of note, students can gain a first-hand look at how human interactions has a direct result on natural processes. For example, artificial selection has resulted in larger animals with bodies that are disproportional (i.e. overly muscular livestock, chicken with breasts so large that they cannot walk due to the excess weight, etc.). This happened in direct response of human manipulating the natural habits of living organisms (i.e. environment, mating habits, feeding habits etc.) in order to retain certain traits. While this often benefits the human population, it can have catastrophic effects on other populations. This activity fits under the evolution unit due to the aforementioned reasons, specifically that a change in one organism often results in the change of another organism (or virus). In this case, it is the student that creates a virus that will have significant health effects on the human population.

Biodiversity

- *Biomimicry: Nature's Finest* – Students design a product that mimics a real life organism; isolating its specific structure that performs a specific function. Students learn about how engineers often imitate nature in the design of innovative new products (see Appendix for complete student handout and teacher notes).

This activity was modified from *Biomimcry: Natural Designs* (Integrated Learning and Teaching Program, 2004) that aligns with Central Community Schools final life science unit: biodiversity. Students apply their knowledge of all the diverse life forms they learned in order to create a product based upon a living organism. Students can use structures based from bacteria, Protista, fungi, plants, and/or animals. Considering they are the largest of the organisms studied, plants and animals are the best represented in the products created by students. A truly accumulative activity, students use knowledge from each of the aforementioned units, and have a final opportunity to explore engineering in a life science course.

With this project students will explore five engineering lessons over the course of one year in a life science curriculum. Considering the local biology curriculum of Central Community Schools, which follows the nature of science, microscopy, cells, genetics, evolution, and biodiversity, these five activities are intended to flow smoothly. Roughly three engineering lessons will be performed in semester one (*Toxic Popcorn* – nature of science, *What is "Nanoscale"/ "Nanotechnology"?* – microscopy, *Effects on the Rate of Photosynthesis in Elodea* – cells) and roughly two engineering activities will be performed in semester two (*Design a Virus* – evolution, *Biomimicry: Nature's Finest* – biodiversity). This provides a solid balance of engineering lessons from one semester to another, as well as content that builds from one engineering lesson to another while remaining consistent with the NGSS life science standards.

Chapter 4 Reflection

This project has successfully met its goal: to develop lessons containing engineering design processes for implementation into a life science course, such as biology. In order to satisfy the NGSS, engineering is to be interwoven within the content standards. Including the aforementioned five activities into the curriculum, the curriculum gets closer to meeting the NGSS. The professional community now has concrete examples that can be used directly in life science classrooms.

Central Community Schools science department, grades 7-12, focused on student understanding of the engineering design process for their professional development. The student goal was as follows: On or before May 5, 2015 as a result of teachers effectively implementing engineering design strategies, 100% of middle and high school students will express a stronger interest in the engineering field as evidenced by the pre and post student survey and show mastery of the 5-step engineering design process as evidenced by formative assessments.

Using *Ask, Imagine, Plan, Create,* and *Improve* as the five steps of the engineering design process, students were subjected to roughly five formative assessments over the course of the 2014-2015 school year. Each formative assessment tasked students with listing the steps of the engineering design process in the proper order. Using a three-tier scale (*Far To Go*, *Meets*, and *Mastery*), student work was graded accordingly. Listing the five steps in the proper order was deemed as *Meets* the goal, while providing further information on the specific actions of each step would be scored as *Mastery*. Anything not meeting these two requirements was scored as *Far to Go*. Initial data was collected after students had experienced at least one engineering activity or had been exposed to the steps of the engineering process and included over 100 7-12 students. This assessment showed 34% of the students rating the lowest on the scale (*Far to Go*), while 43% met the goal, and 23% of the students assessed received *Mastery* rating. Once students had experienced at least four engineering lessons, students who scored at the lowest rating was reduced to 12% as many of those students moved to *Meets* (25%) and the majority of the students achieved *Mastery* (63%). Although we were unable to meet our goal of 100% of students, this suggests that the majority of students (88%) were able to recognize the steps of the engineering design process after performing these steps in their science courses.

Furthermore, using the *Middle and High School STEM-Student Survey* developed by North Carolina State University (Friday Institute for Education Innovation, 2012), 75% of the same population of 7-12 science students showed some interest in engineering and possibly entering engineering-related fields. A suggestion can be made that exposing students to engineering lessons in science courses increased their interest in engineering and the potential to enter engineering related fields.

Anytime curricular activities are developed these activities are untried. It is only with the implementation of these activities in a classroom of students that subsequent changes in the curriculum can be made to perfect these activities. Three of the five activities were performed in the 2014-2015 school year: *Toxic Popcorn*, *Design A Virus*, and *Biomimicry: Nature's Finest*. *Toxic Popcorn* is an activity that I have performed twice, each of the last two years. Students have been very receptive to this activity as students are engaging in engineering practices without realizing it. I have done this on the second or third day of class, as an icebreaker type activity. It is important to have enough space to spread groups around. I learned quickly that more space allows each group to operate independently. If you have four or five groups all tasked with the same problem and materials performing in the same classroom, pretty soon every group will be copying each other. This activity works best if each group can be isolated from one another, this way they can be independent in their thought processes and not be tempted to look at and copy other groups.

The most important aspect of this activity in the conversation that occurs at the end of the lesson that directly follows the group, as selected by their peers, who attempts to save the city. This is where the introduction to the engineering design process occurs, after students reflect on what they did in the activity, and eventually you will provide the steps to the students. Being adequately prepared for that conversation is a must, as this will set the precedent on terminology and attitudes about engineering moving forward with subsequent lessons. I can state that in my first year performing this activity I was ill prepared for this conversation which resulted in me clumsily writing the steps down (*Ask, Imagine, Plan, Create, Improve*) without much expansion of what each of the steps represents. Having an understanding of the engineering design process and which unique steps you would like to use is a must prior to this activity.

I did the *Design a Virus* activity for the first time on a whim in the 2015-2016 school year. Viruses are often a tough pathogen for students to comprehend, especially considering that have certain attributes that are considered non-living and other attributes that are considered to be living. One error I made is I did not provide a handout to students that explained the scenario, instead I said it verbally in class and added it to my virus PowerPoint that I use for note-taking purposes. This resulted in unclear expectations, confusion on the part of the students, as well as a lack of a rubric for what I was looking for in terms of the final product. I had to continuously evolve my expectations and this activity lengthened in duration as a result. Considering my initial explanation was unclear, students were not specific in their explanations of how their virus would perform its functions. For example, in the question on how they were introducing the virus in a population they responded they would use a secret agent, a drone, a cropduster, etc. While technically acceptable, responses were far less specific and scientifically sound. In addition, when students explained what target cell the virus would use and how the virus would enter the target cell students would identify a generalized cell (i.e. nerve cell, muscle cell, blood cell) instead of a specific cell (i.e. keratinocyte, macrophage, Schwann cell, etc.) and were general in how their virus would invade the cell. Viruses often enter cells by attaching to a specific receptor on the target cell. Understanding what receptors are, as well as the structures that bind to receptors such as ligands (in a lock-and-key mechanism) were conceptual pieces that students struggled with. While I had some creative and interesting viruses being created by my students, they often did not align with the cells being attacked and the symptoms provoked. Attention to detail by students, resources provided by the teacher, as well as concrete examples of real life viruses and how they function should alleviate some of the issues found in this lesson. Having the student handout and corresponding rubric should help accordingly.

Biomimicry: Nature's Finest is the third engineering lesson that I have used in my class. In their presentations student examples often did not mimic a real, living organism, instead, they often mimicked an action of an organism and not a specific structure. For example, students may want to create a strong net that mimics a spider's web. However, they are actually mimicking the silk that the spider produces. In actuality, this would be an acceptable product, but their explanation was not as seamless as it should be. Their explanation included that the net mimics the spider, when in reality their biomimicry example mimicked the silk that the spider produces. In that example, the structure and components involved in the production and ejection of silk need to be explained at length, which is where the students did not understand. This lack of specificity is often an issue for students. For example, a student may want to create a helmet that prevents concussions mimicking the skull of a woodpecker. While this is a good initial idea, the skull of a woodpecker is too vague to accurately describe how it can withstand the constant trauma of pecking against the side of a tree. Students needed to be able to describe what about the composition of the woodpecker's skull can actually be mimicked in the production of a helmet? Specifically, it is the increased amount of spongy bone (diploë) in the skull that protects the brain, which could be further researched and developed accordingly. Another example is creating sticky gloves to catch various items. Saying that you will mimic the sticky hands and feet of a frog are much too generalized, what makes the amphibians hands and feet sticky? This is a recurring issue found in student products, an inability to specifically describe the structure mimicked and how it performs its function. I have constantly reworked the rubric for this activity. Being as clear and straightforward with students is a must in regards to expectations being met. Having examples saved from previous years has helped explain these expectations, as well as having resources prepared and ready to go.

As of right now, I have not performed the *What is "Nanoscale"/ "Nanotechnology"?* and *Effects on the Rate of Photosynthesis in Elodea* activities in class. The plan is to perform these activities for the first time in the 2015-2016 school year, which should further aid in my professional growth.

It is unclear if there is an exact number of engineering related lessons that should be performed within a life science course. These five lessons will be the basis for establishing engineering related lessons that will be fully implemented in my biology classes for the 2015-2016 school year. As always, reflection and modification of lessons will be made accordingly in subsequent years.

Completing this project has resulted in my increased understanding of the current literature surrounding the place of engineering within the science curriculum. Specifically, gaining insight into the NGSS and the presumed adoption of them in the coming years has been beneficial for me. Furthermore, I have acquired leadership roles have been obtained as a result of conducting this project, namely the titles of Professional Development Lead Facilitator in Central Community Schools 7-12 Science Department beginning in the 2014-2015 school year as well as Model Teacher for the 2015-2016 school year.

Without this M.A. program and final project, this professional growth and the acquired roles would not have been possible. For example, engineering was a topic of conversation within my science department in the last few years, as word of the NGSS gathered traction. With my first hand exposure to these topics in my M.A. courses, as well as attending a workshop specific to engineering in the K-12 science curriculum, my peers recognized my ensuing knowledge in this content area. This lead to my principal asking me to take this leadership role as well as leading vertical alignment discussions for K-12 science within my district. Lastly, I earned the Model Teacher position as a direct result of my knowledge gained during my M.A. program. During the interview process, I referenced such ideas as constructivism, student-centered, and inquiry-based learning, including the five “E” lesson plan template. While I had a generalized knowledge of these topics prior to my M.A. studies, I now have a fundamental understanding that contributed to my being appointed Model Teacher beginning in the 2015-2016 school year.

While further degrees are not out of the question, earning a M.A. degree in Science Education has been wholly satisfying for me at this point in time. Being appointed as a Professional Development Lead Facilitator and Model Teacher are two leadership roles that have allowed for my professional growth. Being a classroom teacher is still desirable to me, and being taken away from that environment is something that is unappealing at this juncture. One possibility made available from this degree is being able to offer anatomy & physiology as a concurrent course in agreement with the Eastern Iowa Community Colleges. Students in the surrounding area have the potential to earn eight college credits as a result from taking my course for a full year. Teaching at the community college or collegiate level is something that may be a direction for my future professional growth. In the oncoming years I can see myself taking a role as an Instructional Coach outside the classroom, or serving as a science curriculum and/or instructional specialist. Education is a constantly evolving enterprise to which I would be willing to utilize my degree in order to serve my community and its constituents appropriately.

Appendix

Name(s):

Toxic Popcorn!

Engage

[Adapted from *Object Overload: Popcorn*, Deviant Art, website: http://xanyleaves.deviantart.com/art/Object-Overload-Popcorn-445632092]

Oh No! A can of highly toxic popcorn has contaminated a circle approximately 3 feet in diameter. The toxic area extends to the ceiling. If the toxic popcorn is not transferred to a safe container for decontamination, then it will contaminate and destroy the entire city. The popcorn is estimated to have a safe life of exactly 60 minutes before it explodes. It's up to us to save the city!

Inside the circle you will find two containers. One (unsafe) container is half full of the toxic popcorn. The other (safe) container is available for decontamination. Find a way to safely transfer the toxic popcorn from the unsafe container to the safe container, using only the materials provided to you.

- No one may cross the plane of the circle with any part of the body.
- The popcorn and containers cannot cross the plane of the circle. Only the provided materials (ropes and tube) may cross.
- No spills are allowed or the popcorn will explode
- You may use only the materials provided.
- The popcorn must be transferred within 60 minutes or there will be a disaster.

Suggestions

- Work in teams of 4.
- Keep good notes.
- Work for 40 minutes and then each group present to the class to choose one.
- Implement 1 group's idea in the last 5 minutes.

Follow up Questions:

1. Did your solution save the city?

2. What went well?

3. What didn't go well?

4. What was your favorite part and why?

5. What things ("steps") did you do to solve this problem?

References

Boesdorfer, S. (2013). *Toxic Popcorn*.

IEEE. (n.d.). *Toxic Popcorn Design Challenge*. Retrieved from http://tryengineering.org/lesson-plans/toxic-popcorn-design-challenge

Leaves, X. (2015). *Object Overload: Popcorn*. Retrieved from http://xanyleaves.deviantart.com/art/Object-Overload-Popcorn-445632092

Teacher Notes
Toxic Popcorn
Engage

Lab Setup:	None	Easy	**Moderate**	Difficult
Class Time Required:	15 – 30 min	30-45 min	45-60 min	**60 min +**
Reasoning Level:	Easy	**Moderate**	Difficult	
Process Skills:	**Observing**	Measuring	**Comparing**	Collecting Data
	Questioning	**Experimenting**	**Hypothesizing**	Control Variables
Web Connect:	Yes	**No**		

Objective: Students will learn the steps of the engineering design process by developing a process and product to solve the challenge.

Standard(s)-Iowa Core:

Science As Inquiry

- Think critically and logically to make the relationships between evidence and explanations.
- Recognize and analyze alternative explanations and predictions.
- Communicate and defend scientific procedures and explanations.

Standard(s)-NGSS:

HS-ETS1-2. Design a solution to a complex real world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Materials:

<u>Groups</u> (of 4, ideally):

- Containers (Equal Size, 2 Per Group)
- String/Rope (7 ½ Feet, 6-8 Pieces)
- Bicycle Tire Tube – 18" (1 Per Group)
- Pennies (Represents Toxic Popcorn, 100-200 Per Group)
- Hula Hoops (~3-4 Feet in Diameter, 1 per group)

<u>Contaminated Area</u>:

- Containers (Equal Size, 2)
- Popcorn Kernels (Fill ½ of One Cup)
- Hula Hoop (~3-4 Feet in Diameter)

Hazard Warning OR Safety: Students may attempt to eat the popcorn kernels, which may be unsanitary as it can be used from year to year.

Teaching Strategies:

Advanced Preparation: Materials should be bought prior to the class period, and can be re-used from year to year (saving a lot of prep time in subsequent years). Have the *Contaminated Area* set up in the middle of your classroom prior to students entering, being sure they stay clear of the zone of contamination (refer to picture under *Sample Data* below). For testing purposes, each group will receive 2 equal size containers, 6-8 pieces of 7 ½ feet of rope, an 18" bicycle tire tube, 100-200 pennies that represents the toxic popcorn, and a hula hoop. They will mimic the *Contaminated Area* you have set up in the middle of the classroom to perform their testing.

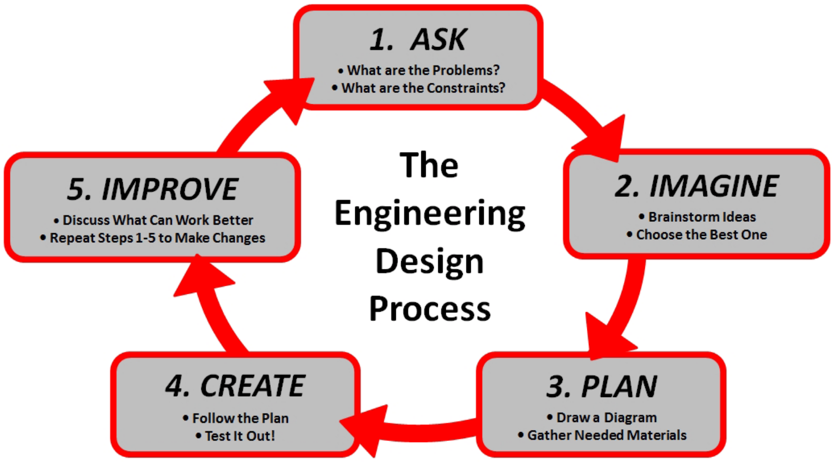
This activity serves as an introduction to the engineering design process, and works best in groups of 4 (but can be done with 3-5 members). It is up to you if you wish to discuss the specific steps of the engineering design process before or after the activity, but by using this as an engagement piece it works better to have a discussion after implementation of students actually doing the process. This should be done relatively early in the school year, as most students will have limited exposure to engineering, particularly within a life science course.

Begin by reading through the scenario to the students, having them follow along on the student sheet. Provide each group with their testing materials, and discuss why they cannot test in the actual toxic zone (it's contaminated!). Students should be aware that they are using similar items to the contaminated zone, but not the exact replicas (which they may want to take into account for their final process). Be sure to tell the students to record all ideas, sketches, etc. that they come up with. Tell the students that they have 60 minutes only to save their city, 40 minutes to design, build, test, etc. and 10 minutes to select the best available option from the class (each group much be prepared to explain their design and process to the class). It is best to have each group spread out as far as possible, so they do not waste time trying to copy other group's ideas. Regular checks should be made to each group so they stay on task, and an online counter can be used so all groups know how much time is remaining. Lastly, the class will vote on which design they believe is the best to save the city. The group chosen will perform their plan, which hopefully is successful. The class will be very excitable in this process, as it's not about one team but the entire class attempting to save the city.

Upon completion of the activity, students should respond to the Summing Up questions. A discussion should follow, introducing the steps of the engineering design process* and engineering in general (why do this in a science class?). Further conversations and extensions can be used accordingly, such as comparing/contrasting the engineering design process to the scientific method, constructing their own versions (i.e. posters) of the engineering design

process, etc. It is important, however, that as a science department you have a common process that all students will be exposed to in order to avoid confusion.
NOTE* - which engineering design process you choose is completely up to you, there are lots of options out there. Here is one such option:

ASK → IMAGINE → PLAN → CREATE → IMPROVE



[Adapted from *The Engineering Design Process,* North Carolina State University, website: http://www.engr.ncsu.edu/theengineeringplace/educators/]

Sample Data:

Set Up	
Tension Example	
Compression Example	

[Adapted from *Toxic Popcorn Design Challenge,* IEEE, website: http://tryengineering.org/sites/default/files/lessons/popcorn.pdf

There are a lot of potential solutions to this problem; encourage students to be creative and unique, and not have every group essentially come up with the same idea. There are ways to make this more difficult, depending on the abilities of your students. You can use a square instead of a circle for the contaminated area, increase the diameter/area of the contaminated area, use more difficult containers for transferring, etc.

Sample Answers to Summing Up:

Encourage students to answer in complete sentences and to record everything. Being an activity that is done on the first few days of school, this is a great way to set expectations for student work. Although there is not a lot of science content in these questions, and it's more opinion based, be sure that they answer the questions fully with complete sentences.

1. Will be dependent upon the group. Generally speaking, every class has one group that is able to save the city, but group-to-group responses will vary.

2. Generally students have success with one portion of this challenge. This may be moving containers, pouring the contents, brainstorming ideas, teamwork, etc.

3. Most often, having controlled pouring of the popcorn from one container to another is the biggest obstacle. Teamwork, brainstorming ideas, etc. can also be a detriment to groups.

4. Being done early in the school year, students have seemed to enjoy this lesson as an ice breaker/introductory activity. Anticipate lots of positive responses from this (i.e. "fun," "meeting students in class," "solving the problem," etc.).

5. Ideally, through all group responses and beginning your discussion, students will have come up with the following (or similar): Ask, Imagine, Plan, Create, Improve.

References

Boesdorfer, S. (2013). *Toxic Popcorn*.

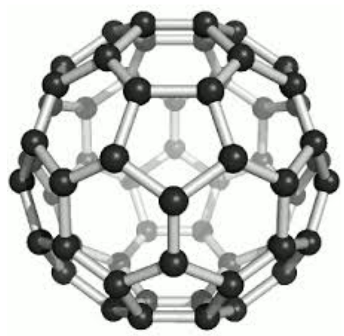
IEEE. (n.d.). *Toxic Popcorn Design Challenge*. Retrieved from http://tryengineering.org/lesson-plans/toxic-popcorn-design-challenge

Leaves, X. (2015). *Object Overload: Popcorn*. Retrieved from http://xanyleaves.deviantart.com/art/Object-Overload-Popcorn-445632092

North Carolina State University. (2015). *The Engineering Design Process*. Retrieved from http://www.engr.ncsu.edu/theengineeringplace/educators/

What is "Nanoscale"/ "Nanotechnology"?

Explore

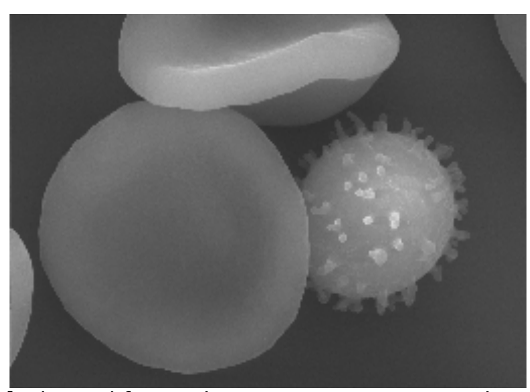


[Adapted from *Nanoparticle Blog,* Particular Customized Material, website: http://nanoparticle-blog.com/page/3]

Imagine being able to observe the motion of a red blood cell as it travels through your blood vessels. What would it be like to observe sodium and chlorine atoms as they approach each other to physically transfer electrons to form a salt crystal or observe the vibration of molecules as the temperature increases in a pot of water? Due to tools or "scopes" that have been developed and improved over the last few decades we can observe situations such as the examples above. The ability to observe, measure, and manipulate materials at the molecular or atomic scale is called **nanotechnology** or **nanoscience**. The prefix "nano" means there is a billionth of that substance. Scientists and engineers can apply "nano" to meters (length), seconds (time), liters (volume), and grams (mass) to represent what is quite obviously a very small quantity. Most often "nano" is applied to the length scale as we measure and talk about nanometers (nm). Individual atoms are smaller than 1 nm in diameter, with it taking about 10 hyrdogen atoms in a row to create a line 1 nm in length. Other atoms are larger than hydrogen but still have diameters less than a nanometer. A typical virus is about 100 nm in diameter and a bacterium is about 1,000 nm in length. The tools or new "scopes" that have allowed us to observe the previously invisible world of the nanoscale is the electron microscope (specifically the Scanning Electron Microscope or SEM).

Scanning Electron Microscope (SEM)

The SEM is a special type of electron microscope that creates images of a sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern to produce 3D images. In a raster scan, an image is cut up into a sequence (usually horizontal) strips called "scan lines." The electrons interact with the atoms that make up the sample and produce signals that provide data about the surface's shape, composition, and even whether it can conduct electricity. The image to the right is human red blood cells and a monocyte (white blood cell type), magnified ~10,000X.



[Adapted from *Electron Microscope Facility*, Dartmouth College, website: http://remf.dartmouth.edu/Blood_cells_SEM/images/14%20BloodMonocyte_1-15-09-2.jpg]

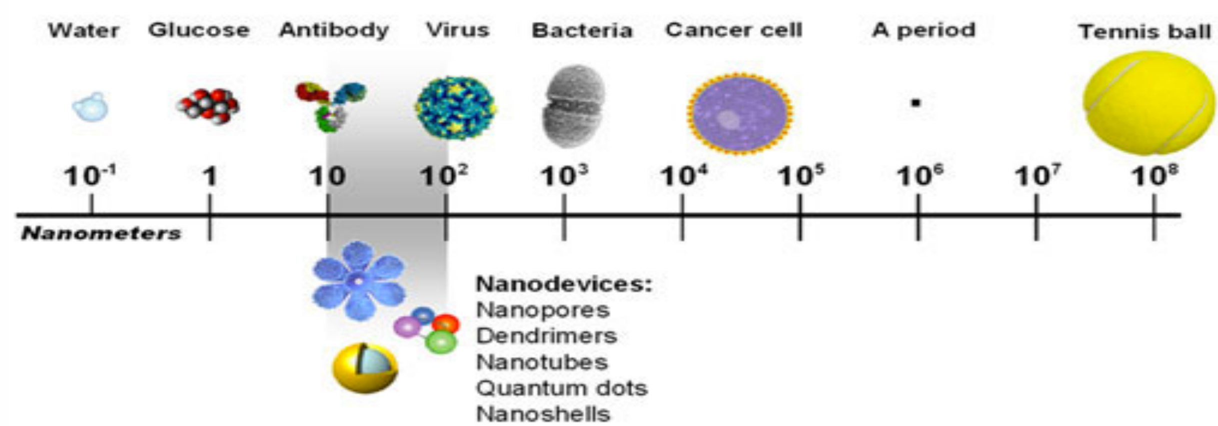
Surface area is the measure of how much exposed area an object has. It is expressed in square units. If an object has flat surfaces, its surface area can be calculated by adding the area of its faces together. Even objects with smooth surfaces, such as spheres, have surface area.

At the nanoscale basic properties of particles may vary significantly from larger particles. This might include mechanical properties, whether the particle conducts electricity, how it reacts to temperature changes, and even how chemical reactions occur. Surface area is one of the factors that changes as particles become smaller. Since chemical reactions usually take place on the surface of a particle, if there is an increased surface area available for reactions, the reaction can be very different.

It can be difficult to visualize how small things are at the nanoscale. The following example may be beneficial to help you comprehend this scale: a bowling ball, billiard ball, tennis ball, golf ball, marble, and a pea. Think about the relative size of these items.

[Adapted from *Exploring at the Nanoscale,* IEEE, website: http://tryengineering.org/sites/default/files/lessons/explorenano.pdf]

Now take a look at the chart below and think about how much smaller the various items are...moving down from the familiar tennis ball. The "." on this page is 1,000,000 microns – quite large in comparison to a virus or a single molecule of water.



[Adapted from *Understanding Nanotechnology,* National Cancer Institute, website: http://nano.cancer.gov/learn/understanding/]

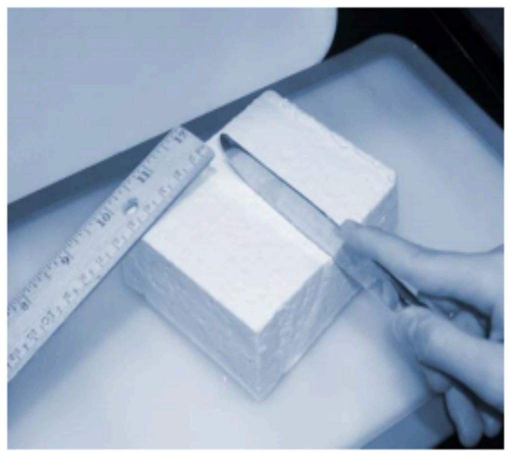
Surface Area Activity

You are a part of a team of engineers who has been given the challenge of evaluating how surface area changes as a material is made smaller. You have been provided with some sheets to read as well as a block of either tofu or gelatin, a cutting surface, a ruler, and a dull knife.

You will need to determine the surface area of the full block, and then the cumulative surface area of smaller block you create by cutting the original block in half, and quarters – down to all blocks created at about ½ inch in width.

Use the chart below to indicate your findings:

# Blocks	1 Block	2 Blocks	4 Blocks	8 Blocks	16 Blocks	32 Blocks	64 Blocks
Surface Area:							

[Adapted from *Exploring at the Nanoscale,* IEEE, website: http://tryengineering.org/sites/default/files/lessons/explorenano.pdf]

Nanoscale Applications Activity

You are part of a team of engineers who has been given the challenge to brainstorm ideas about how nanotechnology might help improve life on Earth. To spur your imagination, your team will first read the following press release about new research in applying silver using nanotechnology to coat surgical equipment:

Breakthrough Antimicrobial Technology for Medical Devices

Strong industry interest in SilvaGard, a breakthrough antimicrobial nanotechnology, has resulted in significant growth for AcryMed, the company that developed and now licenses the technology. Built on years of research in developing silver antimicrobial wound treatments, SilvaGard addresses a still un-met clinical need, preventing the spread of deadly medical device-related infections. By harnessing the advantages of nanotechnology with the broad-spectrum infection-fighting ability of Ionic silver, SilvaGard provides a safe and effective solution to render medical devices impervious to infection causing biofilms.

"The spread of hospital acquired infections is a significant problem that unnecessarily effect millions of U.S. patients each year and adds more than 28 billion dollars to our nation's healthcare costs," said Jack McMaken, president of AcryMed. "Since a large portion of harmful bacteria is harbored on medical devices such as indwelling catheters and implants, manufacturers are extremely interested in finding ways to curtail the role their products play in spreading infections. SilvaGard represents the first significant breakthrough in this area in quite some time."

SilvaGard prevents the spread of device-related infections by depositing antimicrobial silver nanoparticles onto the surfaces of medical devices and thus providing a protective barrier. Studies have shown that SilvaGard is not only safe for use, but also highly effective against a wide spectrum of infection-causing bacteria including MRSA and other antibiotic-resistant "superbugs."

In recent findings presented at the Surgical Infection Society (SIS) meeting, I-Flow's ON-Q SilverSoaker antimicrobial catheter demonstrated a significantly lower risk of developing a surgical site infection in an on-going prospective study of patients undergoing colorectal surgery. The preliminary results captured the outcomes of 120 patients, randomized to either treatment with continuous local anesthetic using the antimicrobial treated ON-Q catheter or to the control treatment employing traditional pain relief. At 30-days post surgery, patients who received treatment with the antimicrobial ON-Q device had a significantly lower incidence of site infections at 0%, as compared to the control group at 22.9%.

[Adapted from *Exploring at the Nanoscale,* IEEE, website:
http://tryengineering.org/sites/default/files/lessons/explorenano.pdf]

Meet as a team and discuss what you learned about nanotechnology and surface area. Then as a group, think about a new application and how you think nanotechnology might make a product, process, or anything better. You can pick any industry such as automotive, or think about a product such as a fabric for clothing.

Prepare a pitch to a potential organization who you will request research funding. You'll need to explain why you think your new nanotechnology application may work, and how it will improve a product or process. This is a formal presentation and you may wish to prepare charts or presentation posters – anything that may impress your potential funders. Be prepared to answer questions from your audience!!

Each student in class may vote for one proposal by any team, other than their own, to be funded. Those presentations with the most votes come in first place!

Summing Up:

1. What application did you develop for nanotechnology?

2. What application of nanotechnology did another team present that you found the most interesting? Why?

3. What is the most interesting aspect of nanotechnology you learned during this lesson?

4. From the group assigned to you (________________________________), what are a few ways in which their nanotechnology could be improved?

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Teacher Notes

What is "Nanoscale"/ "Nanotechnology"?

Explore

Lab Setup:	**None**	Easy	Moderate	Difficult
Class Time Required:	15 – 30 min	30-45 min	45-60 min	**60 min +**
Reasoning Level:	Easy	**Moderate**	Difficult	
Process Skills:	**Observing**	**Measuring**	**Comparing**	Collecting Data
	Questioning	**Experimenting**	**Hypothesizing**	Control Variables
Web Connect:	**Yes**	No		

Objective: Students will explore nanotechnology and how engineers have learned to explore the world at the nanoscale in order to understand exactly how small the nanoscale is, how surface area changes at the nanoscale, and work in teams to develop potential applications of nanotechnology.

Standard(s)-Iowa Core:

Science as Inquiry

- Uses technology and mathematics to improve investigations and communications.
- Think critically and logically to make the relationships between evidence and explanations.
- Communicate and defend scientific procedures and explanations.

Life Science

- Understand and apply knowledge of the cell.

Standard(s)-NGSS:

HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

Materials:

- Computer with Internet access
- Extra firm tofu or gelatin
- Cutting board
- Dull Knife
- Ruler or Measuring Tape
- Paper, Poster Board, etc. for Pitch

Hazard Warning: Safety handling dull knifes.

Teaching Strategies:

Students will work together in teams to explore the increased surface area exposed as items are made smaller and smaller. Students examine and measure large blocks of tofu or gelatin, determining the surface area. Then they slice the block into smaller and smaller pieces, exposing more surfaces, and impacting the surface area. Students also explore the size of small, comparing various items to understand how large a "nano" is. They work as an engineering team to determine a new application of nanotechnology for a product or process of their choice. Teams present concepts and proposals to a group of potential research funders (the class) and each student then votes for the proposal with the most potential. Student teams complete reflection documents.

Students should have a good understanding of the metric system including scale, cells including surface area to volume ratio, as well as basic microscopy including light vs. electron microscopes.

Begin by passing out the student handout sheets. Have them read the first couple of pages to gain an understanding of nanoscale and nanotechnology, including a refresher on surface area. Divide them in groups (2-3 students) and provide them the materials (gelatin or tofu, cutting board, dull knife, ruler and/or measuring tape). Explain that the students must work as a team to determine the surface area of the block of tofu or gelatin at various points (whole, sliced in half, quartered, etc.). Students will first measure the full block and determine the surface area, then cut the block in half and refigure the surface area, then half again, etc. – until there are many tofu blocks of ~½" in width. The purpose of including surface area in this activity is that as the scale becomes smaller, the surface area increases. This is a concept that is necessary for students to make applications at the nanoscale.

Afterwards, the same group of 2-3 students will work to develop a proposal for a new application of nanotechnology. Presentations are made to potential research funders (the class) who vote for the proposal with the most potential. The degree/depth of their new applications of nanotechnology is dependent upon the abilities of your students and amount of class time you wish to devote to this activity. This can range from formal presentations to quick pitches explaining their respective ideas. Sample research website with further information/content include: TryNano (www.trynano.org) and National Nanotechnology Initiative (www.nano.gov) just to name a few.

Sample Data:

Will be entirely dependent upon the size of tofu/gelatin used. Students can measure each block after cutting, or develop (look up) a mathematical formula to help figure surface area values. Their applications of new nanotechnology can have a wide range of ideas...encourage creativity!

Sample Answers to Summing Up:

1. I have yet to perform this activity, but there is a wide range of applications for developing/utilizing nanotechnology. Based upon student's interests, they should brainstorm ways in which products and/or natural materials can be benefitted by coating with various

substances (tie-in to surface area activity). For example, coating baseball bats (or other related items) with a polymer composite can result in a lighter, more durable, and more resilient product. From here, students can further investigate how different polymers may result in different functions.

2. Answers will vary.

3. Answers will vary. I anticipate some reference to the importance of surface area on various materials, potentially leading into the concept (or finding a reference which discusses) surface area to volume ratio. Many students may also reference how important this topic can be in terms of benefitting the everyday lives of human beings and other organisms.

4. Answers will vary. Encourage students to provide substantive feedback to their peers. This forces students to be good audience members, and touches upon the *improve* portion of the engineering design process. Tell students that in order for a group to improve their nanotechnology, they need constructive criticism that is respectful.

References:

Bärsch, I.N. & Israel, B. (n.d.). *Nanoparticle Blog*. Retrieved from http://nanoparticle-blog.com/page/3

Daghlian, C. & Howard, L. (2011). *Dartmouth College Electron Microscope Facility*. Retrieved from http://remf.dartmouth.edu/Blood_cells_SEM/

IEEE. (n.d.). *Exploring at the Nanoscale*. Retrieved from http://tryengineering.org/lesson-plans/exploring-nanoscale

IEEE. (2015). *TryNano*. Retrieved from http://www.trynano.org

National Cancer Institute. (n.d.). *Understanding Nanotechnology*. Retrieved from http://nano.cancer.gov/learn/understanding/

National Nanotechnology Initiative. (2015). *Nano*. Retrieved from http://www.nano.gov

Effects on the Rate of Photosynthesis in *Elodea*

Engineering Design Process: ASK → IMAGINE → PLAN → ***CREATE*** → ***IMPROVE***

Context

Your group of engineers has been consulted by the company, PhotoSynergy to develop an environment that doubles the rate of photosynthesis in *Elodea*. PhotoSynergy wants to affect the rate of photosynthesis as a precursor to potentially resort to artificial photosynthesis as a means of alternative energy. Instead of focusing on recreating plants cells, chloroplasts, chlorophyll, etc. (that's being done by another engineering group) you are to focus on improving the rate of photosynthesis. Ideally, once you have collected your baseline data, PhotoSynergy challenges you to double the rate (or more) of photosynthesis.

PhotoSynergy would like a presentation or report that presents the following:

- An explanation of what is occurring.
- What variables affect the rate of photosynthesis in *Elodea* (count the number of air bubbles produced/min.)? How do they effect it and why?
- What conditions should they set to maximize the rate of photosynthesis?
- Can this method double the rate of photosynthesis on a consistent basis?

Background

Carbon Dioxide + Water → Glucose + Oxygen (Light Energy + Chlorophyll)

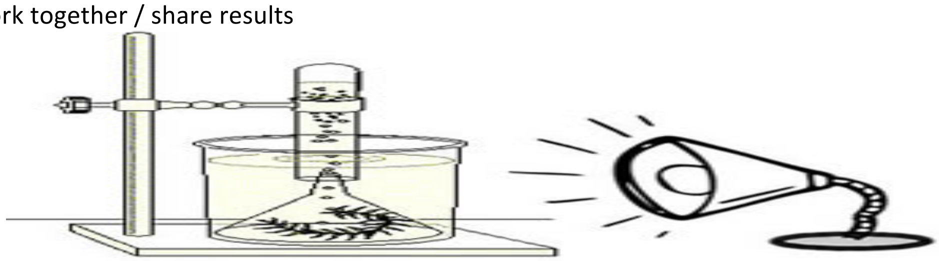
$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2 \text{ (Light Energy + Chlorophyll)}$$

As with all chemical reactions, the rate of reaction will probably change if you change the concentrations of the components, or change the conditions. You will begin by controlling one variable at a time, then progressing to modifying multiple variables to maximize the above chemical reaction.

Materials

Large Beaker	*Elodea*	Lamp
Water (of differing temperatures)	Rubber Bands	Thermometer
Ruler	Scissors	Forceps
Clamp Stand	Stopclock	Balance
Colored Filters/Light Bulbs	Sodium Bicarbonate	Buffer Solutions

Groups may work together / share results



[Adapted from *Exploring the Rate of Photosynthesis*, Biology Corner, website: http://biologycorner.com/worksheets/photosynthesis_rate.html]

Procedure

a Set up the apparatus (see above) and look for a stream of bubbles coming from the cut end of *Elodea*

b Count the number of bubbles produced in 1 minute. Repeat for a second minute. Repeat for a third minute.

c Calculate a mean bubble count – number of bubbles per minute. This is the mean rate of bubble production.

d Attempt to solve PhotoSynergy's request be controlling variables. Be sure to record all data collected. Improve your set up as many times as necessary. You will have the rest of class to double (or more) your baseline data for number of bubbles produced per minute. Once you have controlled for different variables, you may begin to modify multiple variables at once in order to maximize oxygen production. Feel free to converse with other groups about their findings during this process

e Plot data on a line graph. The values of the factor being varied should be on the x axis, and the mean bubble rate in bubbles / minute should be on the y axis.

Roles

Within your group, one person should be assigned as the following:

1. **Manager** – This person makes sure everyone contributes to the group, keeps the group on task, and keeps track of time/constraints.
2. **Recorder** – This person will keep notes, data, and observations from your group's work. This person is also in charge of the actual writing of the final presentations, though the entire group will contribute to its contents.
3. **Communication/Resource Officer** – This person obtains and gets all the materials and resources the group needs. This includes seeking information/resources from other groups if desired. The resource officer from another group should be approached when seeking to share information.
4. **Lab Technician** – This person sets up lab equipment, performs the experiment. Others can be directed to help with any experimentation, but the lab technician should direct them.

RUBRIC

GROUP POINTS	**WAS IT MET?**
Report/Presentation includes accurate explanation of photosynthesis process	
Report/Presentation includes AT LEAST 3 variables that must be changed/controlled	
Report/Presentation explains how each variable affects the process	
Report/Presentation provides a specific process for optimizing the rate of photosynthesis	
Report/Presentation describes the efficiency of the process (2X rate of photosynthesis?)	
Report/Presentation provides data to support claims	
Report/Presentation is professional, neat, correct grammar, etc…	
Group worked well together	
INDIVIDUAL POINTS	
Actively participated in the group	
Fulfilled Group Role	

Total Points _________ / 10

References

Boesdorfer, S. (2013). *Crush a Can for CanCo*.

Biology Corner. (n.d.). *Investigating the Rate of Photosynthesis*. Retrieved from http://biologycorner.com/worksheets/photosynthesis_rate.html

Hindmarsh, J. (2013). *Photosynthesis in Elodea*. Retrieved from https://www.youtube.com/watch?v=yg8vqsBOFMw

Teacher Notes

Effects on the Rate of Photosynthesis in *Elodea*

Application

Lab Setup:	None	Easy	Moderate	**Difficult**
Class Time Required:	15 – 30 min	30-45 min	45-60 min	**60 min +**
Reasoning Level:	Easy	**Moderate**	Difficult	
Process Skills:	**Observing**	**Measuring**	**Comparing**	**Collecting Data**
	Questioning	**Experimenting**	**Hypothesizing**	**Control Variables**
Web Connect:	Yes	**No**		

Objective: Students will improve a design by controlling variables in order to maximize the rate of photosynthesis of the aquatic plant *Elodea*.

Standard(s)-Iowa Core:

Science As Inquiry

- Design and conduct a scientific investigation.
- Formulates and revises scientific explanations and models using logic and evidence.
- Think critically and logically to make the relationships between evidence and explanations.
- Recognize and analyze alternative explanations and predictions.

Life Science

- Understand and apply knowledge of the cell.
- Understand and apply knowledge of the interdependence of organisms.
- Understand and apply knowledge of the interdependence of matter, energy, and organization of living systems.
- Understand and apply knowledge of the interdependence of the behavior of organisms.

Standard(s)-NGSS:

HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Materials:

Large Beaker	*Elodea*	Lamp
Water (of differing temperatures)	Rubber Bands	Thermometer
Ruler	Scissors	Forceps
Clamp Stand	Stopclock	Balance
Colored Filters/Light Bulbs	Sodium Bicarbonate	Buffer Solutions

Hazard Warning: Careful handling live specimen, especially if you have minor cuts or scrapes on your hands. *Elodea* can be an invasive species, so please discard appropriately.

Teaching Strategies:

Advanced Preparation: This freshwater plant is usually available year round (either through a biological supply company, fish and/or pet stores). Obtain *Elodea* a few days in advance of the lab and enhance growth with an artificial light source. *Elodea* is best in an environment of non-chlorinated H_2O with an aerator. To do this let H_2O sit overnight in a container with a large surface area, or simply buy natural spring H_2O.

The apparatus (see below) can be a little tricky to set up, but generally follows the following steps:

(1) Fill the large beaker ¾ full with room temperature, non-chlorinated water

(2) Dissolve 1 g of sodium bicarbonate to the water

(3) Cut 8-12 sprigs of *Elodea* to a length of ~20 cm

(4) Place the sprigs into the mouth of the funnel

(5) Invert the funnel and place it into the container of water, trapping the aquatic plant inside the funnel

(6) Make sure the stem of the funnel is completely submerged in the water (add more water if necessary)

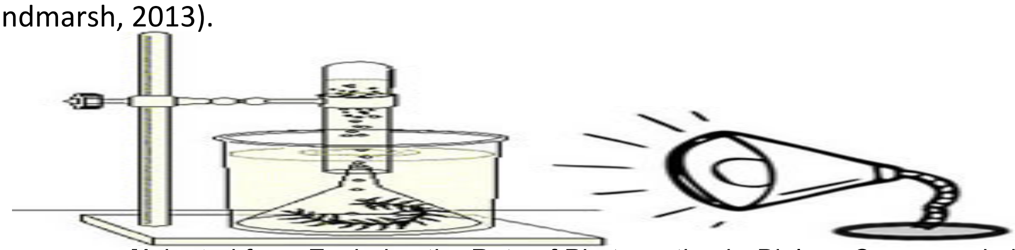
(7) Wrap a rubber band about ¼ of the way down the test tube several times

(8) Submerge the test tube into the water in the container, filling it completely

(9) Invert the test tube in the water and place it over the stem of the funnel while it is still submerge, secure in place with the clamp and stand

(10) Place a fluorescent light source near the container^ and turn it on.

To see a similar, though not exact set-up, visit: https://www.youtube.com/watch?v=yg8vqsBOFMw (Hindmarsh, 2013).



[Adapted from *Exploring the Rate of Photosynthesis*, Biology Corner, website: http://biologycorner.com/worksheets/photosynthesis_rate.html]

^You will need to decide what distance you would like the light source for the initial set-up, as light intensity is one of the limiting factors of photosynthesis.

The apparatus can be set up beforehand and explained to students, or it can be set up at the beginning of class explaining as you go. Students will need to be able to mimic the apparatus you have set up, ultimately being able to control for variables within the set-up. Students should have a fundamental of understanding of the cellular process of photosynthesis, including the chemical equation. Using this knowledge, students should be able to interpret this problem accordingly.

Begin by stating the problem to the students. Again, you need to make a decision to set up the apparatus beforehand and explained to students, or it can be set up at the beginning of class explaining as you go (after the problem has been stated to students). Once each group has the apparatus set-up, be sure that they collect baseline data (as reflected on the student sheet). From there, students essentially have the rest of the block to maximize their O_2-production output within the apparatus by controlling variables. As students get their apparatus set-up and baseline data recorded*, it is imperative to walk around and have conversations with each group about which variables they wish to control for (i.e. light intensity, temperature of H_2O, pH of H_2O, light wavelength, concentration of sodium bicarbonate, etc.). It works best if different groups are using different variables as opposed to students all performing the same task. This may not happen initially, but once they begin conversing they should be testing different variables at that point. Avoid, if possible, all groups working together in a large group testing the same things. While communication between groups is acceptable (and encouraged), be sure that they work independently for the first portion of this activity in order to collect their own baseline data.

*Remember that there are different roles for this activity:

1. **Manager** (makes sure everyone is contributing, keeps the group on task, and keeps track of time/constraints)
2. **Recorder** (keeps notes, data, and observations of all group work; also in charge of writing the final presentations, though the entire group will contribute)
3. **Communication/Resource Officer** (obtains and gets all materials and resources that the group needs, including seeking information/resources from other groups if desired and/or sharing information with other groups)
4. **Lab Technician** (sets up lab equipment, performs the experiment).

Once students begin to culminate their data collection (45-60 min.), they should begin to finalize their report/presentation. With the various roles provided, this should flow fairly seamlessly. The last 15-20 min. (after clean-up) should be devoted to the class reports/presentations. If necessary, the reports/presentations can be finalized over night and performed first thing on the following class period.

Here is the rubric:

RUBRIC

GROUP POINTS	WAS IT MET?
Report/Presentation includes accurate explanation of photosynthesis process	
Report/Presentation includes AT LEAST 3 variables that must be changed/controlled	
Report/Presentation explains how each variable affects the process	
Report/Presentation provides a specific process for optimizing the rate of photosynthesis	
Report/Presentation describes the efficiency of the process (2X rate of photosynthesis?)	
Report/Presentation provides data to support claims	
Report/Presentation is professional, neat, correct grammar, etc…	
Group worked well together	
INDIVIDUAL POINTS	
Actively participated in the group	
Fulfilled Group Role	

Total Points _________ / 10

Sample Data:

I have yet to perform this activity, so no sample data can be provided. Based upon my own experience trying this set-up, anticipate between 2-10 bubbles under "normal" conditions per minute (dependent upon distance of light source to plant). Be sure to have plenty of *Elodea* available.

Generally speaking, there are three primary limiting factors to the rate of photosynthesis: light intensity, CO_2 concentration, and temperature. There are various ways in which these can be increased, so students may reach them in a variety of ways.

Sample Answers to Summing Up:

N/A. Please refer to the rubric to score student work.

References:

Boesdorfer, S. (2013). *Crush a Can for CanCo*.

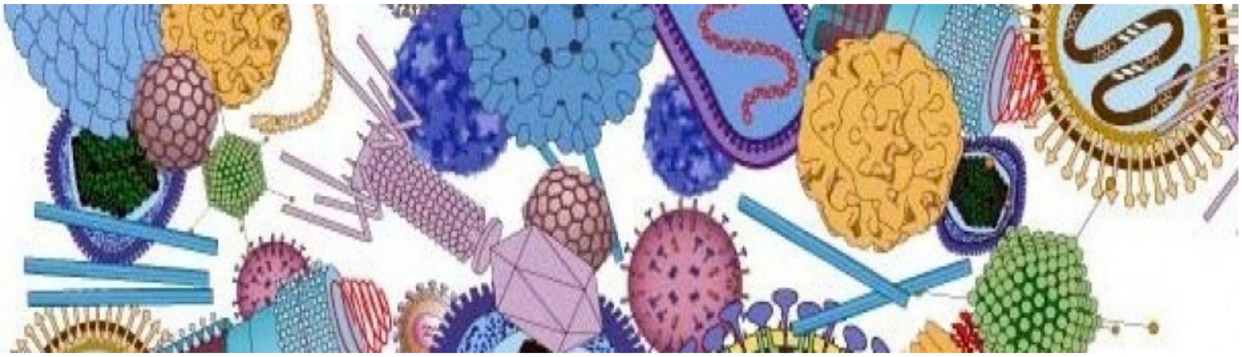
Biology Corner. (n.d.). *Investigating the Rate of Photosynthesis*. Retrieved from http://biologycorner.com/worksheets/photosynthesis_rate.html

Hindmarsh, J. (2013). *Photosynthesis in Elodea*. Retrieved from https://www.youtube.com/watch?v=yg8vqsBOFMw

Name(s):

Design A Virus!

Application



[Adapted from *Virology Spring 2011 Blog,* California Institute of Technology, website: https://virologyspring2011.wordpress.com/]

You are a member of an extremely classified biological engineering research team within the Central Intelligence Agency of the United States Government: **Operation Virenesis**. In response to the looming prospect of **WWIII**, including threats of biowarfare and weapons of mass destruction from rogue nations, you and your team have been tasked with engineering the deadliest virus as a means to threaten these opposing nations against global war. While keeping certain bioethics into consideration, you will not be utilizing the **create** component of the engineering design process. However, utilizing your knowledge and research on existing viral pathogens, you will need to develop a pitch to the President as if this was a real, viable option that could be used as a part of our Nation's Defense System. Feel free to use any resources at your disposal. The specific aspects to be considered include:

- How to introduce the virus within a population?
- How will the virus enter the target cell?
- Once in the cell, what is the means of viral replication?
- What cells are to be targeted by the attacking virus?
- Based upon the cells targeted, what are the intended symptoms of the virus?
- Once an individual is infected, how is the virus transmitted between individuals?
- What is the structure of the virus?

Upon completion of the aforementioned items, you will deliver a quick pitch of your virus to the President of the United States of America [see Rubric]. You have the rest of the day to begin work on this problem; all remaining research and work will be completed outside of class time. You will have roughly two weeks to complete the assigned task. Good luck!!

Biological Engineering Project
"Design A Virus"
Group Grading Rubric

Group Members: ________________________

____

Criteria	High Performance	Average	Low Performance
Pitch	Speakers have obviously prepared for the pitch. All aspects of the biological engineering task are covered. Presentation provokes interest.	Speakers may not have prepared for the presentation. The pitch flows for the most part, but an aspect of the biological engineering task is absent. Presentation provokes interest.	Speakers have not prepared for the pitch. The presentation does not flow well, is missing aspects of the biological engineering task, and/or the presentation does not provoke interest.
	_______/5	____/4	____/3
Introduction of Virus Within a Population	Dispersal means are logical, creative, and consistent for widespread delivery of the virus within a population. Secrecy is maintained - being nonchalant in the delivery process.	Dispersal means may be logical, creative, and/or nonchalant, but missing one or more of the specific criteria.	Method of virus delivery within a population is absent.
	_______/5	____/4	____/3
Viral Replication (Cell(s) Affected)	The specific cell(s) in which the virus attacks is identified, including the specific receptors that allow viral entry into the cell. Method of viral replication is mentioned (i.e. RNA/DNA based virus).	The specific cell(s) in which the virus attacks is identified, BUT the specific receptors that allow viral entry into the cell is missing (or vice versa). Method of viral replication is mentioned (i.e. DNA/RNA based virus)	The cell(s) in which the virus attacks may be identified, BUT the cell type is not specific enough (including absence of receptors) to warrant complete understanding. Viral replication is absent (i.e. DNA/RNA based virus).
	_______/10	____/7.5	____/5
Viral Symptoms	Clear symptoms of the immune response are identified and are consistent with the cells affected. Mode of death is suggested and makes sense in light of the symptoms and onset of disease.	Clear symptoms of the immune response are identified, but are not consistent with the cells affected. Mode of death may or may not be suggested.	Symptoms are not identified, but may include the cells affected (or vice versa). Mode of death may or may not be suggested, but does not relate to any sound scientific basis.
	_______/5	____/4	____/3
Viral Transmission	Spread of the disease from one subject to another is identified, consistent with the symptoms. Viral transmission creates fear within an entire population, including its government. An epidemic is possible by causing a widespread, high death toll.	Spread of the disease from one subject to another is identified, BUT not consistent with the symptoms. Viral transmission may or may not create fear within the population, including its government. An epidemic may be possible by causing a widespread, high death toll.	Spread of the disease may or may not be identified. If it is present, it is *not* consistent with the symptoms. Viral transmission may or may not create fear within the population, including its government. An epidemic is not possible.
	_______/5	____/4	____/3
Viral Structure	An illustration (picture, sketch, image, etc...) of the virus is present. Protein based receptors (ligands) are included emphasizing viral entry into a cell.	An illustration (picture, sketch, image, etc...) of the virus is present, but may not be unique and/or scientifically valid. Protein based receptors (ligands) are included emphasizing viral entry into a cell.	An illustration (picture, sketch, image, etc...) of the virus is absent.
	_______/5	____/4	____/3

TOTAL: __________ / 35

Teacher Notes

Design A Virus

Application?

Lab Setup:	**None**	Easy	Moderate	Difficult
Class Time Required:	15 – 30 min	30-45 min	45-60 min	**60 min +**
Reasoning Level:	Easy	Moderate	**Difficult**	
Process Skills:	Observing	Measuring	**Comparing**	Collecting Data
	Questioning	Experimenting	**Hypothesizing**	Control Variables
Web Connect:	**Yes**	No		

Objective: Students will demonstrate their knowledge of viral pathogens by engineering the world's deadliest virus.

Standard(s)-Iowa Core:

Science as Inquiry

- Formulates and revises scientific explanation and models using logic and evidence.
- Think critically and logically to make the relationships between evidence and explanations.
- Recognize and analyze alternative explanations and predictions.
- Communicate and defend scientific procedures and explanations.

Life Science

- Understand and apply knowledge of the cell.
- Understand and apply knowledge of biological evolution.
- Understand and apply knowledge of the interdependence of the behavior of organisms.

Standard(s)-NGSS:

HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.

HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

HS-ETS1-2. Design a solution to a complex real world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Materials:

- Paper*
- Pencil*
- Markers or colored pencils*
- Computer with Internet access

*if creating illustration by hand. Some students may select to build a physical model of their virus. While not required, any materials they use may need to be supplied by themselves.

Hazard Warning: N/A.

Teaching Strategies:

This activity should be completed after culmination of a basic unit on genetics, including DNA/RNA structure and protein synthesis. Basic knowledge of viruses and the human immune response should be covered as well.

Begin by reading the prompt on the student handout sheet. The core of this activity is for students to create the deadliest virus, as a means to threaten other countries to avoid going to war*. The activity presents a great opportunity to discuss items such as bioethics, biowarfare, etc. Those conversations can occur before, during, or upon completion of the activity. As previously mentioned, students should have had exposure to genetics, pathogens (viral, bacterial, protozoan, fungal), as well as the human immune response. This is intended to be an open-ended, high-level process for student to delve into. One recommendation is to provide one class period for the introduction of the activity, while students will spend the majority of work outside of class time (more of a project in that regard) to finish the activity. The pitch component should take no more than 30 minutes per section, depending on the size of your class. Pitches are not intended to be lengthy, more of a highly organized condensed content delivery (the scenario is they are pitching it to the President, so it should be short and sweet).

*While intended as a hypothetical situation, certain students (or families) may object to this scenario as it may be deemed unethical. While the intent is to provoke student interest, it may be counter-productive for certain students. One example modification is for students to take an existing virus without a known vaccine. Have students develop a mechanism to stop the virus from performing its functions inside the host organism and attacking its cells. At its core, students will be performing the engineering design process as well as hitting on all of the intended standards.

With the pitches, students are encouraged to create PPT's, Prezi's or any other technological means in order to organize their content; this will give it more of a professional look. Since an illustration is a requirement, students may select to do this by hand, build a model, etc. Remind students that with their pitch they will need to incorporate their viral structure in some manner, so if their sketch is too small or done poorly, the "President" would deem this to be unprofessional even before the content is delivered. Be sure to speak to the rubric and the specifics of what you are looking for. They include:

- How to introduce the virus within a population?
- How will the virus enter the target cell?
- Once in the cell, what is the means of viral replication?
- What cells are to be targeted by the attacking virus?
- Based upon the cells targeted, what are the intended symptoms of the virus?
- Once an individual is infected, how is the virus transmitted between individuals?
- What is the structure of the virus?

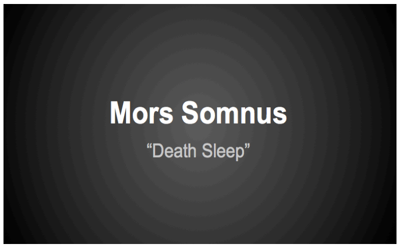
Sample Data:

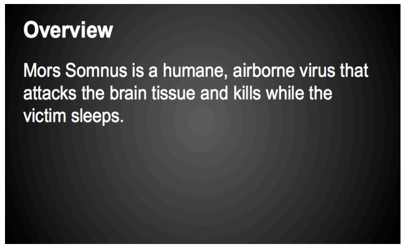
- **How to introduce the virus within a population?** A drone, kamikaze agent, secret agent, etc. were common responses to this prompt. While technically acceptable, responses were far less specific then necessary. Encourage students to be scientifically sound and creative with this prompt.
- **How will the virus enter the target cell?** Another prompt where students were not very specific. Encourage students to find a specific receptor found on the target cell that a viral ligand could attach to in order to gain entry. Specifics beyond this point in not necessary for this age group, but a review of receptor and ligand may be necessary.
- **Once in the cell, what is the means of viral replication?** Review lytic vs. lysogenic cycle, DNA vs. RNA based viruses, retroviruses, etc.
- **What cells are to be targeted by the attacking virus?** Again, specificity is key. “Blood cells,” “white blood cells,” “muscle cells,” etc. are far too vague for this assignment.
- **Based upon the cells targeted, what are the intended symptoms of the virus?** Too often, students had deadly symptoms that would certainly kill the infected individual, but it was often a stretch to tie the symptoms with the targeted cells.
- **Once an individual is infected, how is the virus transmitted between individuals?** Airborne, waterborne, contaminated food, handling dead bodies, etc. were common responses. While sound in logic, what allows the virus to remain suspended in air? water? etc. Specificity is key.
- **What is the structure of the virus?** Students can be as creative as possible here, but their ligand that attaches to the target cell receptor should be included.

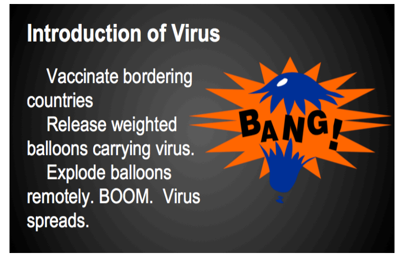
Students often mimicked viruses they know (Ebola, HIV, Influenza, etc.) but lacked on the specific components. For example, they want their virus to cause a runny nose and sneezing in order to spread the disease, but what characteristics of the virus assures this will happen? I would be happy to share sample student projects, please feel free to contact me.

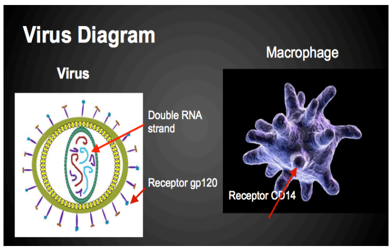
Sample Answers to Summing Up:

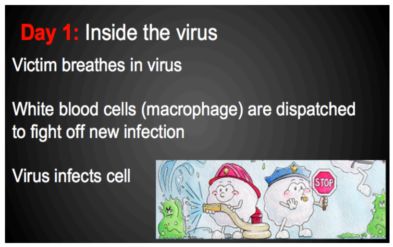
N/A. Please refer to the rubric to score student work. Below you will find a sample of a student’s pitch.

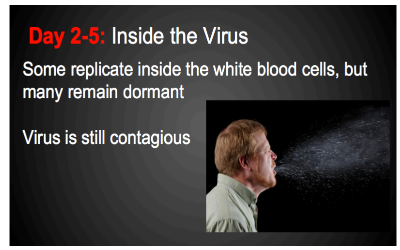


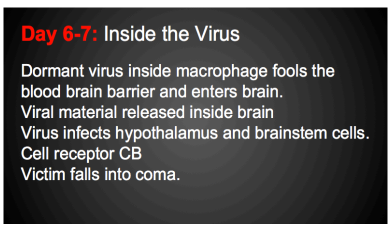


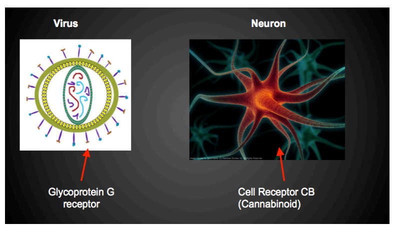


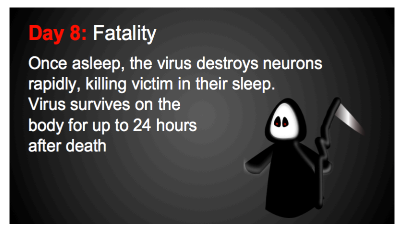


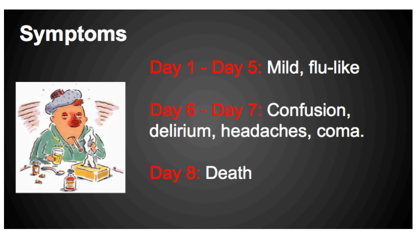


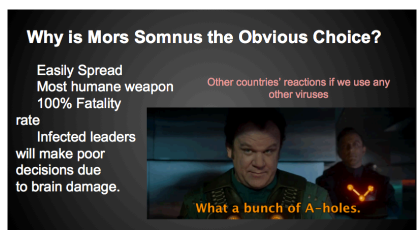












Pitch: 5/5
Introduction of Virus Within a Population: 4/5
Viral Replication (Cell(s) Affected): 10/10
Viral Symptoms: 4.5/5
Viral Transmission: 4.5/5
Viral Structure: 5/5

TOTAL: 33/35 – 94.29% (A)

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Name(s):

NATURE'S FINEST

Engineers often use the natural world as inspiration for design. Biologically inspired designs include planes and boats, sonar and radar, medical imaging devices, biomedical technologies like prosthetics, and water and pollution treatment processes. **Biomimicry** has resulted in many creative products such as materials inspired by the slick leaves of the lotus plant and its natural capacity to wash away dirt particles with rain as well as the Velcro® hook-and-loop system inspired by the prickly plant burrs that stick to our clothes.

Learning Objectives

After this activity, students should be able to:

- *Define biomimicry*
- *Explain how engineers use biomimicry to design innovative new products*
- *List examples of engineered products that were inspired by nature*
- *Use biomimicry to develop an idea for a new product*

Materials List

Each student needs:

- Paper (Graph Paper - *Optional*)
- Pencil
- Markers or colored pencils
- Ruler
- Computer with Internet access

Introduction/Motivation

Do you know what the word "*biomimicry*" means? Let's break down the word into more understandable parts. "*Bio*" means life and "*mimicry*" means to imitate. So, *biomimicry* means to imitate life or nature. Biomimicry is a way of learning from nature. It is a way to observe nature in action and use that knowledge to inspire new ideas. Engineers often use these ideas to develop cool new products or better ways to do things to help people.

Velcro® was invented after a man took a very close look at those little prickly seeds that stick to your clothing when you walk through a field. Water filters are designed like animal cell membranes that let certain things pass through while others are kept out. Though planes do not flap their wings like birds, their shapes and the principles of keeping a plane in flight are the same as bird wings. People have also created adhesives that mimic the fascinating and sticky surface of gecko or lizard's five-toed feet. Radar and sonar navigation technology as well as medical imaging was inspired by the echolocation abilities of bats. The solar cells that make up solar panels are designed to mimic the way leaves collect energy from the sun.

Engineers have also used biomimicry of animals to design things like prosthetics, agriculture methods, navigation tools, and even running shoes. Darcy Winslow, the general manager of environmental business opportunities at Nike, Inc. said, "The extent to which the natural world can provide technological solutions for the types of product performance characteristics we must provide are virtually unlimited. Biomimicry still requires exploration, innovation and creativity, but by thinking like or working with a biologist we must learn to ask a different set of questions and look to nature for inspiration and learning opportunities." [Source: The Science Creative Quarterly - http://www.scq.ubc.ca/?p=321]

Engineers definitely look to nature for inspiration and learning opportunities. Another way that engineers learn from nature is to figure out ways to address the pollution that results from making and using products. Nature has a well-defined way of taking care of its trash, such as dead animals and leaves. Everything in nature is used, even its waste products. Sometimes natural waste becomes food for others animals or breaks down into soil nutrients available for reuse. This is a very important model for engineers; we can learn from nature to recycle our resources and not leave a contaminated mess behind every time we make something.

Biomimicry is a process in which you ask the question, "What would nature do here?" Today we are going to be design engineers who use the biomimicry of animals or other organisms to come up with a new invention!

Vocabulary/Definitions

Biomicry: Copying or imitating the special characteristics of naturally existing things (animals, plants, etc.) in human-made designs, products and systems. (From bio, meaning life, and mimesis, meaning to imitate).

Design: To form or conceive in the mind. To make drawings, sketches or plans for a work. To design a new product. To design an improved process.

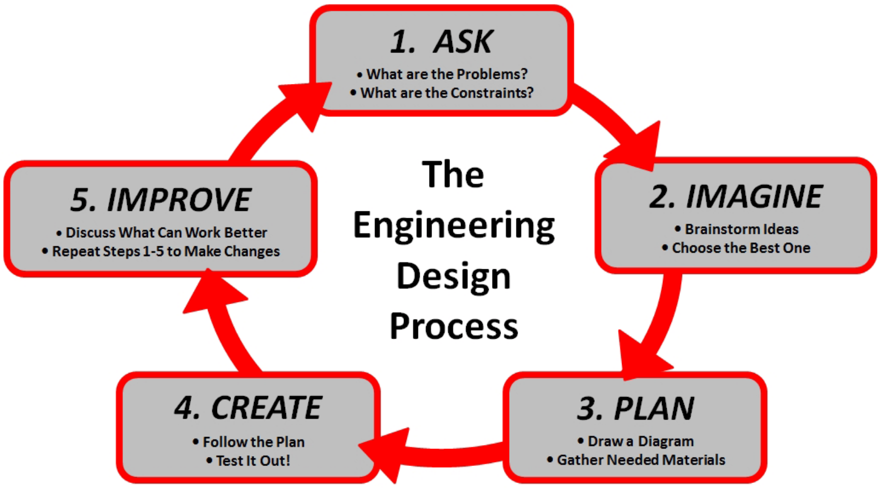
Engineer: A person who applies scientific and mathematical principles to creative and practical ends such as the design, manufacture and operation of efficient and economical structures, machines, processes and systems.

Function: The special, normal or proper action of a part of an organism (i.e. physiology).

Model: (noun) A standard or example for imitation or comparison. (verb) To simulate, make or construct something to help visualize or learn about something else (as the living human body, a process or an ecosystem) that cannot be directly observed or experimented upon.

Structure: An arrangement or organization of parts to form various hierarchical levels of an organism (i.e. anatomy).

Engineering Design Process: The design, build and test loop used by engineers. The steps of the design process include: 1) Ask *[What are the problems? What are the constraints]* 2) Imagine *[Brainstorm ideas; Choose the best one]* 3) Plan *[Draw a diagram; Gather needed materials]* 4) Create *[Follow the plan; Test it out!]* 5) Improve *[Discuss what can work better; Repeat steps 1-5 to make changes]*



[Adapted from *The Engineering Design Process,* North Carolina State University, website: http://www.engr.ncsu.edu/theengineeringplace/educators/]

Procedure

Background: More on Biomimicry

People have called on nature's inspiration throughout humans' history. By observing organisms, particularly animals, plants and their natural processes, we gain insight into what works and what does not. For engineers, these observations are helpful in both the *design process* and inspiring new inventions using natural technologies.

List examples of products inspired by biomimicry [No Resources]

Using the text above, list as many examples as you can of biomimicry:

List examples of products inspired by biomimicry [With Resources]

Using the resources online, or others you may find, include **5** detailed examples of products inspired by biomimicry:

1.

2.

3.

4.

5.

Activity

1. **List** three things you have as an interest. These interests can be anything (i.e. sports equipment, music, clothes, games, furniture, cars, etc.)

2. Next, you will be selected a partner based upon a common interest.

3. You will have 10 minutes to brainstorm with your partner to come up with possible ideas for designs within your interest topic using biomimicry of an animal or other organism. This type of brainstorming and building on each other's ideas is an important step in engineering a new, innovative product. Brainstorming guidelines:

- No negative comments allowed.
- Encourage wild ideas.
- All ideas are recorded.
- Stay focused on the topic.
- One conversation at a time.
- Build on the ideas of others.

Remember, the only bad thing about an idea is if it's the only one!

4. You will have the remaining block to design and sketch* your new product that uses biomimicry (keep ALL sketches; do NOT erase anything!). Be as detailed as possible. Label parts and materials in your design. Your final product design *should* be drawn to scale using graph paper, including at least two separate sketches at differing views of your product (i.e. side view vs. bird's eye view), and should have relevance to societal problems. Your final product will be completed outside of class, and will be due roughly one month from today

***You may use an electronic creation instead of a sketch**

5. Once you have finished your design, make a list of the special features of your design and which animal(s) or organism(s) inspired those features. Include a brief paragraph that "sells" your product to potential clients, including its usefulness to society.

6. Role-play as an engineering company and present your biomimicry designs to the class (due dates to be announced in class and are subject to change). You will also post your product (via a scanned .pdf or electronic file) on Edmodo.

7. You will be assigned two groups to provide feedback on their product via Edmodo. This is an important step in engineering a new, innovative product. Improving, or optimizing engineering related products is essential to maximizing the quality of a product.

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Integrated Teaching and Learning Program. (2004). *Biomimicry: Natural Designs*. Retrieved from https://www.teachengineering.org/view_activity.php?url=collection/cub_/activities/cub_bio/cub_bio_lesson05_activity1.xml

North Carolina State University. (2015). *The Engineering Design Process*. Retrieved from http://www.engr.ncsu.edu/theengineeringplace/educators/

Nature's Finest Engineering Rubric **Group Members: __________________________**

____

Grading Rubric

Criteria	**High Performance**	**Average**	**Low Performance**
Presentation	Speakers have obviously prepared for the presentation (duration between 30 – 90 seconds, no extended pauses, no excess reference to notes, no excess stuttering, etc.). The sales pitch flows with a clearly defined **role**, identified **audience** and the **topic** is addressed clearly and accurately. Presentation provokes interest.	Speakers may not have prepared for the presentation. The advertisement flows for the most part, but could be improved in one area. Presentation provokes interest.	Speakers have not prepared for the advertisement. The presentation does not flow well and the presentation does not provoke interest.
	_______/10	____/8	____/6
Conventions and Cohesiveness	**No errors** in spelling, grammar, capitalization or punctuation. Biomimicry prototype ireasonable, feasible, while also focusing on a societal need. The prototype has a pleasant look, feel, and design.	Few errors in spelling, grammar, capitalization or punctuation. Biomimicry prototype may be reasonable, but not feasible (or vice versa). It has a decent look, feel, and design, but may not have a societal need.	Several errors in spelling, grammar, capitalization and punctuation. Biomimicry prototype is neither reasonable, nor feasible. The look, feel, and design is poor and does not have a societal need.
	_______/5	____/4	____/3
Biomimicry Model Prototype	Includes all of the following: - **Scale** (Mathematically Correct) - **Graph Paper Used** - **Perspectives** (Inclusion of two differing view points for the prototype (i.e. side view vs. bird's eye view) - **Detail** (Parts labeled, color added; generally speaking – it is evident that time and effort was put forth)	Includes all of the following, but some aspects could be improved: - **Scale** (Mathematically Correct) - **Graph Paper Used** - **Perspectives** (Inclusion of two differing view points for the prototype (i.e. side view vs. bird's eye view) - **Detail** (Parts labeled, color added; generally speaking – it is evident that time and effort was put forth)	Missing some of the following AND/OR some aspects could be improved: - **Scale** (Mathematically Correct) - **Graph Paper Used** - **Perspectives** (Inclusion of two differing view points for the prototype (i.e. side view vs. bird's eye view) - **Detail** (Parts labeled, color added; generally speaking – it is evident that time and effort was put forth)
	_______/15	____/12	____/9
Feedback to Peer Groups	Student feedback is insightful, respectful, as well as applicable. A minimum of three specific suggestions for optimization of peer prototypes is included.	Student feedback is provided, but lacking in one of the categories (insightful, respectful, or applicable). Suggestions are made, but may not be specific or include less than three.	Student feedback may not be provided, or if so it is significantly lacking in insight, respect, and application. Specific suggestions are lacking, or not provided.
	_______/10	____/8	____/6

TOTAL: _________ / 40

Teacher Notes
Nature's Finest
Application

Lab Setup:	**None**	Easy	Moderate	Difficult
Class Time Required:	15 – 30 min	30-45 min	45-60 min	**60 min +**
Reasoning Level:	Easy	**Moderate**	Difficult	
Process Skills:	**Observing**	**Measuring**	**Comparing**	Collecting Data
	Questioning	**Experimenting**	Hypothesizing	Control Variables
Web Connect:	**Yes**	No		

Objective: Students will define biomimicry, explain how engineers use biomimicry to design innovative new products, list examples of engineered products that were inspired by nature, and use biomimicry to develop an idea for a new product.

Standard(s)-Iowa Core:

Science as Inquiry

- Formulates and revises scientific explanation and models using logic and evidence.
- Think critically and logically to make the relationships between evidence and explanations.
- Communicate and defend scientific procedures and explanations.

Life Science

- Understand and apply knowledge of the cell.
- Understand and apply knowledge of biological evolution.

Standard(s)-NGSS:

HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

HS-ETS1-2. Design a solution to a complex real world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Materials:

- Paper (Graph Paper)
- Pencil
- Markers or colored pencils
- Ruler
- Computer with Internet access

Hazard Warning: None.

Teaching Strategies:

This activity should be done as an end of the school year project, with students utilizing their newfound knowledge of the kingdoms of life. Students should have been exposed to the vast majority of the NGSS and Iowa Core Curriculum for life science (HS-LS1 From Molecules to Organisms: Structures and Processes, HS-LS2 Ecosystems: Interactions, Energy, and Dynamics**,** HS-LS3 Heredity: Inheritance and Variation of Traits, and HS-LS4 Biological Evolution: Unity and Diversity). Students need to have prior knowledge of structure vs. function (including on both micro vs. macro scales), heredity (including how DNA (in the form of genes) ultimately codes for protein (which produces traits)), and evolution (including how genes evolve over time leading to new variations of traits).

Students should have studied every major kingdom of life, including bacteria (*Eubacteria* & *Archaeabacteria*), *Protista*, *Fungi*, *Plantae*, and lastly *Animalia.* This includes all of the invertebrate phyla (*Porifera, Cnidaria, Platyhelminthes, Nematoda, Mollusca, Annelida, Arthropoda,* & *Echinodermata*) and vertebrate classes (Amphibians, Birds, Fish, Mammals, & Reptiles). The Animal Unit will be most fresh in students mind, which includes a survey of every invertebrate phyla including major topics such as body plan (i.e. symmetry), specialized cells/tissues/structures, habitat, diet, evolutionary milestones, etc. Students will either observe live specimen (i.e. *Hydra, Dugesia, Lumbricus)* or perform a dissection (i.e. *Ascaris*, Clam, Earthworm, Crayfish, & Sea Star) with their invertebrate animal surveys, which is essential for observation of specialized structures and functions. For the vertebrates, students should have touched upon the history, evolution, key characteristics, organ systems, diversity, and classification of the vertebrate classes. They will also perform dissections (i.e. frog, sparrow, perch, rat, and chameleon) on the vertebrate classes. It should be apparent in students' minds the diversity of life and the specialized structures shown by various groups of organisms.

Begin by engaging in an informal conversation about biomimicry. This will include specific examples that aid in students day to day lives, including their personal lives [see below]. From there, disperse the student handout sheets, and explain the initial basics of biomimicry. The sheets contain an "Introduction/Motivation" section as well, providing a background on biomimicry. One of the first few items on the student handout is brainstorming examples of biomimicry related products, and then conducting brief research on further example products inspired by nature. At this point, introduce the project logistics, which is primarily to design a product based on biomimicry.

Introduce the rubric, so students are aware as to what the expectations are in regards to grading this activity. Considering students have already been exposed to the engineering design process throughout the course of the year (this is an end of the school year activity), state to them that this activity focuses on the ***Plan*** and ***Improve*** steps of the engineering design process (or whichever specific engineering design process you have implemented). To a lesser extent, the ***Ask*** and ***Imagine*** steps are touched upon as well. The ***Create*** step is the only step that is truly omitted from the design process, based upon material and monetary constraints. The **Improve** step is covered to a degree by providing feedback to other groups, although the groups receiving the suggestions will not apply that to their current product for this activity (although it could be done if you wish). The larger idea at play here is that students come across quite a few products inspired by biomimicry in their lives. Ultimately, engineers try to solve problems that humans face in society. Engineering, including bioengineering (i.e. biomimicry), is a part of something that students will encounter, either directly or indirectly, during the course of their lives. In a perfect world, activities like this one will inspire students to enter an engineering related field as their career, with the intention to better our society at large.

Students will be grouped in pairs, selected by their interest. In this activity, students will list which items they are interested in (i.e. sports equipment, music, cars, etc.) and be paired accordingly. Formative assessment will be done via conversations with students while they are working, asking questions and observing their work. Direct questions related to structure vs. function and steps of the engineering design process will be of note. Inquiring students, as opposed to telling them the answer, is the key. Student understanding will be largely derived from the rubric, which will evaluate their prototype, presentation skills, and feedback delivered to their peers.

The timeline of this activity can be dependent upon multiple variables. Generally, a class period used to introduce the activity and being brainstorming ideas is beneficial. Further class periods can be used for student's development of their biomimicry prototype, or this development can be performed outside of class. At the end of this activity, students will have created a sketch of their product drawn to scale using graph paper. Students can build an actual prototype if wanted, but any materials they need would be upon them to gather. Students are then to "pitch" their products to their classmates, in a 30-90 second window. This is not intended to be a presentation, more of an elevator pitch, as if they were pitching it to a major corporation on the ride up an elevator or as a commercial. Upon completion of their pitch, students/groups will provide feedback to a different group, touching upon the **improve** step of the engineering design process (although not completing unless you would like to add this step to the lesson).

Teachers should be familiar with the engineering design process, which is on the student handout sheet. They should also have a decent understanding of the specifics of biomimicry, including examples. There are resources listed on the student handout sheet, but here are some specific examples:

Example inventions based on or inspired by animals:

- Airplanes modeled after **birds** (wing and body shapes, falcon beak)
- **Fish**-inspired scales that easily slide over each other to enable the morphing airplane wings
- Boat hulls designed after the shapes of **fish**
- Submarine and boats hull material that imitates **dolphin** and **shark** skin membranes
- Radar and sonar navigation technology and medical imaging inspired by the echo-location abilities of **bats**
- Swimsuit, triathlon and bobsled clothing fabric made with woven ribbing and texture to reduce drag while maintaining movement, mimics **shark's** skin

- Adhesives for microelectronics and space applications inspired by the powerful adhesion abilities of **geckos** and **lizards**
- Water filters designed like **animal cell membranes** to let certain things pass through while others are kept out
- Running shoes with technology learned from studying the mechanics of **animal feet**
- Super strong and waterproof silk fibers made without toxic chemicals by **spiders**
- Ceramics and windshields, after the mother of pearl material made by **abalone mussels**
- Underwater glue for slippery surfaces, as made by **mussels**
- Anti-reflective, anti-glare film used for flat panel displays, touch screens, lamps, and phone and PDA lenses replicates the nano-structures found in the eyes of night flying **moths**
- A better ice pick for mountain climbers designed after the **woodpecker**.
- Glow sticks made with light-up chemicals, just like **fireflies**
- Very efficient pumps and exhaust fans applying the spiraling geometric pattern found in **nautilus sea shells**, galaxies and whirlpools

Example inventions based on or inspired by plants

- Hook and loop material (Velcro®) inspired by **cockleburs**
- Solar cells inspired by **plant leaves**
- A wind-driven planetary rover design that maximize drag, seen in the **tumbleweed**
- Self-cleaning exterior paint, tiles, window glass and umbrella fabric inspired by the slick leaves of the **lotus flower plant** and its natural ability to wash away dirt particles in the rain
- Reduced-drag propeller designs inspired by the spiral shape of **kelp**, which moves with the current rather than fight it, so much less energy is required to move water or a ship
- Filter and clean water like a **marsh**

Sample Data:

- **List three things you have as an interest.** Accept any/all answers to this prompt. Possible examples include sports equipment, games, furniture, music, clothing, cars, etc.
- **Select your partner based upon a common interest.** There are other ways that you can choose to select partners (they can be assigned, randomly chosen, etc.). Based upon their lists, partners will have to come to agreement on a topic that may or may not be of common interest. If you do choose to select on common interest, there is a chance that a few partners may not have the exact same common interest. You can remediate this by intervening and helping them agree upon a 2nd or 3rd interest that is shared by both partners.
- **You will have 10 minutes to brainstorm...** Put a timer on a smart board or announce to the class that they have 10 minutes only to brainstorm possible ideas. Give them reminders at 5 and 1 minutes remaining. Reiterate the brainstorming guidelines (no negative comments allowed, encourage wild ideas, all ideas recorded, stay focused on the topic, one conversation at a time, and build on the ideas of others).
- **Design and sketch your idea**. Refer to rubric (drawn to scale, use of graph paper, differing points of view, and detail (parts labeled, color added, etc.). The use of an

electronic creation utilizing some software program is encouraged, but not expected. Allow students the ability to utilize resources and creativity.

- **List of special features**. This should be in paragraph form and more or less serve as an abstract for their elevator pitch.
- **Elevator pitch**. This is intended as a 30 – 90 second pitch that summarizes their creation and how it serves as societal need.
- **Student feedback**. Students will provide feedback to a group assigned to them by the teacher. This forces students to be good audience members, and touches upon the *improve* portion of the engineering design process. Students often will say "good job," or "well done" for this portion, which is not insightful. Tell students that in order for a group to improve their product, they need constructive criticism that is respectful.

The possibilities are endless in terms of the products that can be created. Popular items have included sports equipment (i.e. gloves mimicking the adhesive ("sticky") qualities of amphibian hands and feet, helmets mimicking the cranium of a woodpecker to reduce blunt force trauma), military equipment (i.e. camouflage clothing mimicking the ability of certain organisms to change their color/texture to their surroundings such as cephalopods, armor mimicking the exoskeleton of arthropods), amongst various other endless possibilities.

Sample Answers to Summing Up:

N/A. Please refer to the rubric to score student work.

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