TEACHING BIOLOGY WITH ENGINEERING PRACTICES

By

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ABSTRACT

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The Next Generation Science Standards (NGSS) expresses a vision of science education that requires students to not only have an understanding of science concepts but be able to investigate the natural world through process of science inquiry or to solve meaningful problems though the practices of engineering design. While incorporating engineering practices into our science curriculum will soon be requirement of the new state standards, there is little research published as to how this should be implemented in a biology classroom. The goal of this study was to measure the effectiveness of incorporating engineering design into a biology curriculum on student understanding of engineering practices and science content knowledge. The results of this study indicate that the integration of engineering design in a biology curriculum has a positive effect on student's science content knowledge as well as their understanding of engineering design principles.

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Introduction

Engineering Instruction

The world is dynamic and competitive. Today's students will have a multitude of opportunities and challenges awaiting them upon completion of their K-12 education. In order for our nation to compete in the global economy, American students need a solid foundation in Science, Technology, Engineering, and Math, otherwise known as STEM education. Our President, Barack Obama, has emphasized the importance of STEM education to American students "…our nation's success depends on strengthening America's role as the world's engine of discovery and innovation". "… (Our) future depends on their ability to harness the creativity and dynamism and insight of a new generation. And that leadership tomorrow depends on how we educate our students today, especially in science, technology, engineering and math" (Obama 2010). As technology advances and industry grows, there will be a greater demand on for workers with STEM training.

In contrast to our great need for scientists and engineers, several problems are arising about our education system about the quantity, quality, and diversity of our future engineering talent. "Students are not prepared to meet government standards and even less prepared to pursue careers in science" (Ellefson, 2008). According to the 2009 Nation's Report card which is an assessment designed to measure students' knowledge of three broad content areas: physical science, life science, and Earth science as defined by the NAEP science framework, only 21% of U.S. high school students achieved at or above proficient scores, 39% achieved basic scores, and 40% failed to attain a basic level of proficiency (Nationsreportcard.gov). Similarly, the ACT reported in 2012 that only 31% of high school graduates are academically ready for college coursework in science (ACT.org)

While the overall enrollment in undergraduate engineering programs has increased 28% from 2004 to 2013, there is still an issue of gender and ethnic diversity among students enrolling in these courses. The gap between the percentage of males and females enrolling is large, 80.1% to 19.9% respectively. And when comparing the enrollment by ethnicity, the numbers are slightly more equitable but minorities only make up 37.6% of enrollees (Yoder, 2013). Given the need and concerns about out STEM education, it is important to consider ways to improve our K-12 educational curriculum to advance engineering education for all students.

Why Teach Through Engineering Design?

Many educators define "engineering design" in different ways. Dym's definition articulated well the many ideas encompassed in the phrase:

> "Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints (Dym et al., 2005).

For the typical high school student, "engineering design" means a process used to make something that solves a problem. Why should our science curriculum be taught through the lens of engineering design? There are at least three significant reasons. First, it is an effective way to teach science. Secondly it promotes cross-curricular learning of all subjects, specifically science and math. Finally, it is a motivating way to learning.

Teaching using engineering design, specifically through the use of problem-based learning, is one of the best-researched instructional innovations and has been found to increase student understanding of content knowledge, particularly in the form of long-term retention, as well as increase student motivation and performance (Carr, 2011). Other research has found that incorporating engineering design into the curriculum gave students opportunities to learn the process of science while developing an understanding of the conceptual structure of science disciples (Bybee, 2011). Engineering design also promotes questioning and inquiry, which develops the ability to reason, particularly with math and science content (Carr, 2011). Science and engineering practices are parallel and complementary to each other and are mutually reinforcing.

The present K-12 curriculum often forces students to learn in an unconnected manner. A high school student may take a class for science, a separate class for math, and a third for social studies with little or no connections between them. Engineering can act as bridge between all of the different subjects. The goal of engineering design is to develop a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria such as functionality, cost, safety, and aesthetics. The optimal choice depends on how well the proposed solutions meet the criteria (Bybee, 2011). In order for engineers to design the optimal choice, they must have a well rounded awareness for many things outside of science and math. For example, designing a seatbelt for an automobile requires an understanding mechanics to design a functioning devise, human physiology to make it as safe as possible, and psychology to design it in a way that will make likely that the customer will use it.

A third reason for using engineering design in the science curriculum is motivation. Engineering design activities and goals can be intrinsically motivating because they engage a natural desire to make something and they tap into the curiosity that comes from wanting to learn how things work (Brophy, 2008).

Curriculum: The Missing "E" and the NGSS

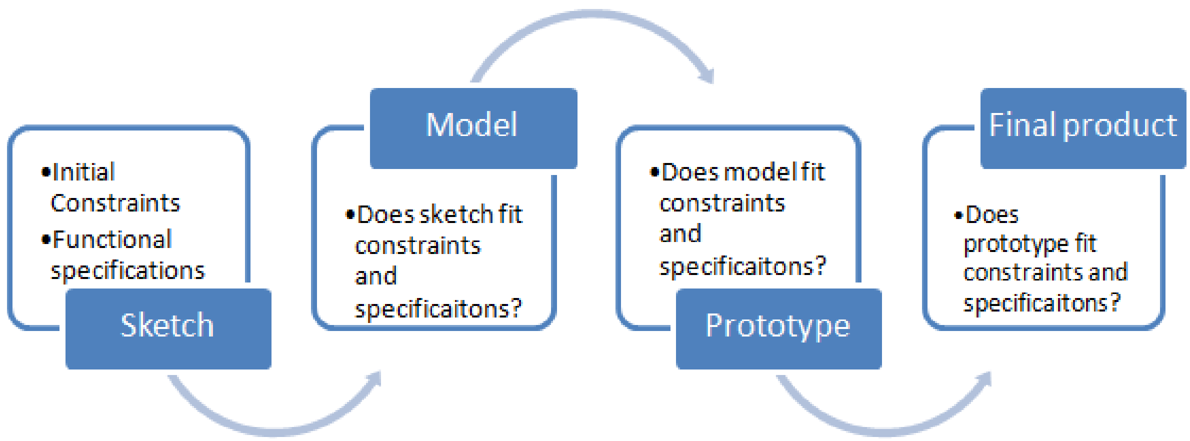
What gets taught in the K-12 classroom is often a function of what get emphasized in national and state content standards in combination with what is assessed on state-mandated achievement tests (ibid), such as the Michigan Educational Assessment Program (MEAP) or the ACT, which are state mandated tests. Therefore it is important to ask what parts of "E" from STEM education are currently required by our national and state standards. The current curriculum that is adopted by the State of Michigan is the High School Content Expectation's (HSCE's). While there are benchmarks for scientific inquiry, which are related to engineering, there are no true engineering design principles included in our current curriculum. The potential future for Michigan's science curriculum is the Next Generation Science Standards (NGSS). The NGSS is based on *A Framework for K-12 Science Education* released by the National Research Council in 2011(Krajcik, 2012). The *Framework* identifies eight scientific and engineering practices that should be used in science classrooms (NGSS appendix F). The term "practice" is used in place of a term such as "skills" to emphasize that engaging in scientific investigations requires not only skill but also knowledge that is specific to each practice (NRC *Framework*, 2012). The eight practices of science and engineering are listed below:

1. Asking question (for science) and defining problems (for engineers)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics, computer technology, and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in arguments from evidence
8. Obtaining, evaluating, and communicating information.

For clarification, a basic practice of engineers when *defining a problem* is to ask questions to clarify the problem, determine criteria for a successful solution, and identify constraints. When engineers design solutions, their proposal is the result of a process that balanced the competing criteria of desired function, technical feasibility, cost, safety, aesthetics, and compliance with legal requirements (NGSS appendix F).

How will this affect teaching in the classroom? The biggest shift will be the expectation for students to construct and revise models based on new evidence, to predict and explain phenomena and to test solutions to various design problems (Krajcik, 2012). Figure 1 shows how the design process can be organized. As the initial idea is introduced, an engineer decides what the constraints and functional specification are and as the design is constructed, it is evaluated and improved upon until it satisfies the specifications. This approach is different than our previous curriculum, which focused on scientific inquiry; the NGSS will widen the scope to the more expansive idea of “scientific and engineering practices”. This will be beneficial to students because “when students engage in scientific and engineering practices, activities become the basis for learning about experiments, data and evidence, social discourse, models and tools, and mathematics and for developing the ability to evaluate knowledge claims, conduct empirical investigations, and develop explanations” (Bybee, 2011).

Figure 1: The Design Process



Science and engineering overlap in many ways but the goals of each are different. Science proposes questions about the natural world and proposes answers in the form of evidence-based explanations. Engineering identifies problems of human needs and aspirations and proposes solutions in the form of new products and processes. Science and engineering are parallel and complementary (ibid). So why is there an emphasis on engineering in the new science curriculum? When solving an engineering problem, students are required to apply their knowledge of science in order to construct a functioning or representative model. In the process of designing and testing models, students enhance their understanding of basic scientific principles while developing an appreciation and understanding of engineering, math, and technology (Kimmel, 2002). This idea is also supported by Rodger Bybee: “Given the inclusion of engineering in the science standards and an understanding of the difference in aims, the practices complete one another and should be mutually reinforcing in curricula and instructions” (Bybee, 2011).

Problem-Based Learning

Problem solving skills are an integral part of engineering design but more importantly, an important part of learning in general. A study of problems with medical education found that students could not integrate subject-matter from different medical disciplines and they lacked the ability to make appropriate use of what they have learned (Barrows & Tamblyn, 1980). This is not unique to medical students. Another study found that high school students performing laboratory experiments became so caught up in carrying out the prescribed task that they failed to think deeply about the underlying science concepts (Schmidt, 1983). Schmidt goes on to say that, "people that do not possess problem solving skills possess knowledge that they seem unable to apply. They know information but cannot use it". Also, studies conducted on highly structured activities, where procedures were specified and results were known, found that students were often not able to relate the activities to everyday life (Marx, Blumenfeld and Krajcik ,1997)

The weakness of many highly-structured tasks is that there is not much thinking generated by the students. Even with scripted inquiry, there are major limitations on the students to ability to define problems and propose scientific investigations (Mehalik, 2008). One way to address these concerns is with problem-based learning (PBL) by modeling student's academic projects by pursuing real life problems. Because students work on a problem that is situated in real-life context, they are better able to construct links between school science and the science required to solve real-world problems (Yager and McCormack, 1989)

Characteristics of PBL include using an ill-structured problem (a problem with no one correct way to solve) to guide the learning agenda, having a teacher act as a metacognitive coach, and students working in collaborative groups (Chin, 2005). Four design principles appear to be especially important in the implementation of PBL instruction (Barron et al., 1998):

1. Defining learning-appropriate goals that lead to deep understanding
2. Providing scaffolds that support student learning
3. Ensuring opportunities for formative self-assessment and revision
4. Developing social structure that promote participation

By incorporating PBL into a curriculum, students become more independent, self directed learners and improve their problem solving skills, but they also more readily learn the content of the course in which the PBL strategies are employed (Hmelo-Silver, 2004).

Integrating both PBL strategies and engineering strategies into a curriculum simultaneously should not be difficult as they share many of the same core ideas. Both approaches attempt to solve a real-world problem and with students reflecting on their experiences or outcome and assessing its effectiveness.

This Study

The goal of this study was to measure the effectiveness of incorporating engineering practices into a biology curriculum on student understanding of engineering practices and science content knowledge as well as increase motivation. The hypothesis for this study was that by incorporating engineering design practices into a biology curriculum, students would show a statistically significant increase in their understanding of engineering principles and biology content.

Demographics

This study was conducted during the 2013-2014 school year at Holt High School in Holt, Michigan, a suburb just south of Lansing, Michigan. As per the latest count information (2014), the High School, which is a 10-12 building, has 1302 students. The student population is approximately 66% White, 12% African-American, 12% Hispanic, 3% Asian, and 7% multiracial. The participating students were primarily sophomores enrolled in three section of the 10th grade biology course, all of which were taught by the author. Of the 85 students that were enrolled in biology, 48 returned the consent form (Appendix A) indicating their participation in the study.

Implementation

Overview

To conduct this study, students were given "Engineering Challenges" that were embedded over the course of the first two units in the fall semester of 2013 in a 10th grade biology class. These two units are taught as a case study of several Michigan campers that mysterious have fallen ill and have died from unknown causes. Through this case study students learn how to use the scientific method, how to use microscopes, understanding the characteristics of living things, the structure and function of the digestive system, and the structure and function of nutrients and enzymes (More information about the case study can be found in Appendix B). The "Engineering Challenges" were designed to help students learn or experiences one or more of the "Engineering Practices" described in the NGSS, as well as learn the course content. The order of the unit topics, as well as the timing for each of the "Engineering Challenges", is listed in Table 1.

Table 1: An overview of what was taught and assessed during this study

Unit Topic	"Engineering Challenges" and Assessments	Engineering Practice Assessed
Unit Introduction	Pre-test (given before unit is started)	All
Normal course work: Scientific method, microscopes, case study introduction, and defining what it means to be sick (2 Weeks)		
Homeostasis (3 Days)	-Homeostasis pretest -Homeostasis Engineering Challenge -Homeostasis post test	-Planning and carrying out an investigation -Analyzing and interpreting data -Engaging in Argument from evidence
Normal course work: Students take observation of "pathogen", determine if it is alive (3 Days)		

Table 1: (Cont'd)

Characteristics of Living Things (2 Days)	**-Engineering Challenge: Metabolism of sugar by yeast**	**-Planning and carrying out an investigation -Analyzing and interpreting data -Engaging in Argument from evidence**
Normal course work: Students use Koch's Postulates to determine if "pathogen" is causing the illness (2 Days)		
Characteristics of Living Things (3 Days)	-Engineering Challenge: Water filtration lab	-Asking questions and defining problems -Designing solutions
Normal course work: Students identify what kingdom the "pathogen" belongs to, then do research to identify the species. (2 Days) END OF UNIT 1		
Begin Unit 2 **Normal course work:** Students determine what body system our "pathogen" is affecting. After learning about all of the body systems, students determine that it is the digestive system that is affected. (4 days)		
Digestion (1 week)	-Digestion pretest -Digestion Engineering Challenge -Digestion post test	-Developing and using models
Normal course work: While students are learning about digestion, they also learn about the function of nutrients and enzymes. (1 week)		
Enzyme Reaction Rates (2 Days)	Experiment not done due to lab constraints	-Planning and carrying out an investigation -Using Mathematics and computational thinking -Analyzing and interpreting data -Engaging in Argument from evidence
Unit summative Assessment **END OF UNIT 2**	Post-test (given at the conclusion of the unit)	All

Engineering Design Process for this Study

The “Engineering Challenges” developed for this study required students to use the engineering design process similar to what is shown in Figure 1 and also similar to Barron’s four design principles for PBL’s. The engineering design process that was simplified for use in this study is as follows:

1. Identify the problem (Usually done by the teacher in this study)
2. Identify criteria and constraints
3. Develop possible solutions (brainstorm)
4. Construct model, prototype, or testing apparatus
5. Evaluate if design meets criteria
6. Completion or modify design

Engineering Pre and Post Assessment

Student improvement of engineering concepts was measured by using a combination of engineering pre and post test and engineering challenge. The engineering pre- and post test, shown in Appendix C with its rubric, was given at the beginning of the first unit and again at the end of the second unit. The response to each question was graded 1 to 4 according to the rubric. Table 2 shows which engineering practice(s) from the NGSS each question was assessing. It should be noted that question 2 was not scored as students misunderstood how they were expected to respond and questions 8 and 9 were scored together.

Table 2: Engineering concept or practice assessed by each question.

Question	Concept or Engineering Practice tested for.
1	Basic understanding of an Engineer
3	Differences between a scientist and an engineer
4	Differences between a scientist and an engineer
5	Developing and using models
6a	Planning and carrying out investigations

Question	Concept or Engineering Practice tested for.
6b	Planning and carrying out investigations and interpreting data
6c	Constructing explanations and designing solutions
7	Analyzing and interpreting data
8 & 9	Engaging in arguments from evidence
10	Using mathematics and computational thinking

Homeostasis Pre and Post Assessment

The homeostasis pre and post test can be found in Appendix D along with its rubric. It was given before instruction of homeostasis started and again at the end of the unit as a part of the unit assessment. The response for each question was graded 1 to 5 according the rubric.

Digestion Pre and Post Assessment

The digestion pre and post test, shown in Appendix E, was given before instruction of the digestive system started and again after the conclusion of the "Engineering Challenge" of developing a model of the digestive system. The assessment was for students to tell the story of a cheeseburger that has eating as it travels through the digestive system. While the assessment is only one question, it should be noted that students were expected to explain what happened in each organ as the food traveled. The response for each question was graded 1 to 5 according the rubric.

Engineering Design and Supporting Conclusion

In two of the "Engineering Challenges", (Engineering Challenge: Homoeostasis and the Engineering Challenge: What food does our pathogen prefer? Appendices F and G respectively) students were assessed on the engineering practices *Plan and Carry out an Investigation* and *Engage in Argument from Evidence*. *Plan and Carry out an Investigation* was assessed by their "experimental design" and graded on a scale of 1 to 3 according the rubric found at the end of each lab. *Engage in Argument from Evidence* was assessed by their "analysis" and graded on a scale of 1 to 3 according the rubric found at the end of each lab.

Lessons for Engineering Challenges

The *Homeostasis Engineering Challenge* lab (Appendix F) introduced students to some of the practices of engineers and scientists, specifically: planning and carrying out investigations, analyzing and interpreting data, engaging in argument from evidence, and obtaining, evaluating and communicating information. In this lab, students were challenged to design a way to test for and measure that living things undergo homeostasis and then support their findings with the evidence that they gathered. Students were allowed a day to plan and brainstorm one solution the first day and a second day to carry out their investigation. Students were told the constraints for the challenge; specifically what pieces of lab equipment were available to them, such as forehead thermometers, stop watches, and Vernier probes like oxygen and carbon dioxide sensors but were encouraged to bring in any materials that they thought they might need. The lesson plan for this challenge can be found in Appendix F. An example of a student performing a homeostasis experiment is shown in figure 2.

Figure 2: A student performing a homeostasis challenge.

The "*What food does our 'pathogen' prefer?"* lab (Appendix G), again challenged students to use some of the practices of engineers, specifically: defining a problem, planning and carrying out investigations, analyzing and interpreting data, engaging in argument from evidence, and obtaining, evaluating and communicating information. As a part of the continuing case study, the students discovered that our "pathogen" is infecting the sick campers and is indeed alive. Their task was to design an investigation to show if our "pathogen" (represented by live yeast) showed a characteristic of living things, respiration, and if they preferred one type of sugar over another. Students were told the constraints of the challenge; specifically, lab equipment that was available to them, such as oxygen and carbon dioxide sensors and bromothymol blue solution (BTB), but were encouraged to bring in any materials that they thought they might need. Students were assessed on their ability to show, from their evidence, that our pathogen indeed went through respiration and preferred one type of sugar over another. Lesson plans for this challenge can be found in Appendix G.

With the *Water filtration* challenge (Appendix H), students were assessed on the engineering practice *design a solution* by designing a water filtration system that could remove the pathogens found in the water from our case study. Students were allowed a day to plan and brainstorm and a second day to carry out their investigation. Students were told the constraints of the experiment and were told that they had access to certain materials and pieces of equipment, such as gravel, sand, activated charcoal, coffee filters, ring stands, 12 ounce plastic bottles, but were encouraged to bring in any materials that they thought they might need. The water was deemed “clean” if no yeast cells were seen under the microscope by the teacher. Students were assessed on this project on whether they were successful or unsuccessful at cleaning the water and were also monitored for their number of attempts it took to be successful. Examples of student projects can be seen in figure 3.

Figure 3: An example of a student project for the *Water Filtration Challenge*

For the *Digestion Engineering Challenge* (Appendix I), students were tested on the engineering practice *develop a model* by construction a two or three dimensional model of the digestive system. Students were allowed a day to plan and brainstorm and several days to construct their models. They were also given a rubric, highlighting all of the things that were expected to be in their models. Students were assessed on the inclusion and accurate representation of all of the items from the "What I will be looking for" section of their handout (Appendix I). Examples of student work on the *Digestion Engineering Challenge* can be seen in figure 5.

Figure 4: Examples of student work on the *Digestion Engineering Challenge*

After completion of the all the Engineering Challenges, the post test was administered.

Results

The results have been divided into two sections. The first section is the results for the assessments of student understanding of engineering practices and the second section is results that are pertaining to the students understanding of specific scientific concepts. For statistical analysis, all averages are compared using a paired, single tailed t-test and were considered statistically different if the p value is less than 0.05.

Engineering Practices

The first analysis of the data was a comparison between the averages for each question of the Engineering pretest and the post test (Table 3, n=47). Each question showed an increase in its average score from the pre to the post test. Of the increases, all showed statistically significant gains except for questions 6 and 10. A synopsis of what engineering practice each question on the pre and post test was testing for can be seen in Table 2.

Table 3: Average scores for the engineering pre and post test, for each question.

Question	Pre 1	Post 1	Pre 3	Post 3	Pre 4	Post 4	Pre 5	Post 5	Pre 6a	Post 6a
AVE (range 1-4)	1.96	2.81	1.85	2.91	2.79	3.34	2.38	2.74	2.51	3.11
p value	<0.000		<0.000		0.0066		0.0052		<0.000	

Question	Pre 6b	Post 6b	Pre 6c	Post 6c	Pre 8&9	Post 8&9	Pre 10	Post 10
AVE (range 1-4)	3.28	3.53	2.19	2.55	2.38	2.94	2.17	2.34
p value	0.0505		0.0227		0.00541		0.394	

An analysis was also done on two of the engineering challenges that were designed and conducted by the students. Table 4 (n=46) shows a comparison of the improvement from the first experiment the students performed (*Homeostasis*) to the second experiment (*What food does our pathogen prefer?*). The averages of the overall scores, the scores for their experimental designs, and their conclusions all increased but only the score for the experimental designs were statistically different.

Table 4: Analysis of the first experiment compared to the second experiment.

	Overall Score for 1st Experiment (range 1-14)	Overall Score for 2nd Experiment (range 1-14)	Experimental design 1st Experiment (range 1-3)	Experimental design 2nd Experiment (range 1-3)	Conclusion 1st Experiment (range 1-3)	Conclusion 2nd Experiment (range 1-3)
AVE	12.52	12.71	1.74	2.41	1.87	2.07
p value	0.24		<0.000		0.076	

Science Content

An analysis was done on the student's overall understanding of homeostasis and human digestion. For homeostasis, average scores for each question of the pre and post test were compared, as shown in Table 5 (n=47). For all three questions there was a statistically significant increase the average scores.

Table 5: Homeostasis pre and post test average scores for all students.

Question	Pre 1	Post 1	Pre 2	Post 2	Pre 3	Post 3
AVE (range 1-5)	1.44	3.81	1.10	3.91	1	4.75
p value	<0.000		<0.000		<0.000	

Table 6 shows the average scores for the pre and post digestion tests. This showed a statistically significant increase from pre to post test. Table 6 has an n=48.

Table 6: Digestion pre and post test average scores

Question	Pre	Post
AVE (range 1-40)	12.67	33.58
p value	<0.000	

An analysis was done on the student's performance on the pre and post tests in comparison to their digestive system modeling project, which is shown in table 7. When comparing the pre test to the project, the averages are statistically different. When comparing the project to the post test, the averages are nearly identical and statistically are not different from each other. Table 7 has an n=44.

Table 7: Digestion pre and post test compared with project scores.

Question	Pre	Project	Project	Post
AVE	12.67	33.4	33.4	33.58
P value	<0.000		0.298	

Discussion

The working hypothesis for this study was that the incorporation of engineering practices into a biology curriculum would increase students understanding of engineering principles and science content, as indicated by pre and post test comparison, over the period of instruction. This appears to be supported by the data that were collected.

For the understanding of engineering principles, Table 2 shows that students made a statistically significant increase on all but two of the questions from the engineering pre and post tests. The first of the two questions that did not show a statistically significant increase (question 6) was a question asking students to list variables that an engineer would have to consider when designing a windmill. It can be assumed that the lack of a significant increase is due to the fact that defining variables is a skill that students have practiced in previous science classes and therefore are already performing at high level. This is supported by the data as this question had high score on the pretest. The second question was an open ended question asking the students if they could think of a way to use mathematics to help them compare two sets of numbers. While anecdotal, it seems to the author that the reason for the insignificant gain on this question may be that some students fear or dislike of the subject of mathematics. Many of the "incorrect" responses made by the students were statements of how much they disliked the subject rather than an actually attempting to answer the question.

While improvements on the Engineering Pre and Post test showed that student growth in this area was significant, evidence of improvement of student performances on engineering challenges are inconclusive. It was expected that between the first and the second challenge, students would improve their abilities to design and conduct an investigation and support their conclusions with data that they collected. As shown in Table 4, students improved their scores in all three categories measured (overall lab score, experimental design score, and conclusion score) but only one category (engineering design) indicated a statistically significant increase. Additionally, the increase in the experimental design scores can be explained by the fact that the second experiment only had a limited number of ways that it could be tested so therefore was easier for the students to design the experiments.

For the analysis of student growth in the area of science content knowledge, improvements from science content pre to post test were used as a measurement of student learning. When analyzing student growth in knowledge of homeostasis, Table 4 indicates that students' scores rose dramatically (at least 50% improvement) for all three of the pre and post question comparison. The most significant increase was in the students being able to name and describe two types of feedback systems. The vast improvement in this area could be attributed to the *Homeostasis Engineering Challenge* where students were required to show that living things undergo homeostasis and provided evidence of a feedback mechanism.

In an analysis of the results for the digestion pre and post test questions, the class averages rose dramatically (52% increase). Between the pre and post tests, the students engineering challenge tasked them with making a model of the digestive system. When comparing how students performed on this challenge to how they performed on the post test (Table 6) the averages are almost identical and statistically the same. This would indicate that this project does an extremely good job at preparing students for the final assessment.

Conclusion

Mitigating factors

A difficulty that was experienced during this study was determining how much the teacher should help the students plan and design their engineering projects. Evidence collected by David Jonassen (2011) suggests that ill-structured problems are difficult for students to start because they are uncertain how to approach the problem. This was experienced to a certain degree on each of the engineering challenges presented in the study described here. The instructor wanted to give students enough freedom to come up with their own way of solving the problem but would often find frustrated students that had no idea where to begin. According to Ennis and Greszly (1991), an integral part of the engineering process is that the background research should be student driven and students should be allowed time to comprehend the information they collected. Unfortunately, time constraints prevented this from being a realistic option and student were, in most cases, only allowed a day or two for researching design.

Time

It is clear from the literature (Hynes 2011, Ennis and Greszly 1991) that allowing students to experience a true engineering design process is a time consuming procedure. There are numerous engineering design cycles that have been determined by different researchers Morgan Hynes (2011) writes of a nine step “Engineering Design Process” that she refers to as an EDP, Arther Eisenkraft describes a similar process but in five steps, and David Jonassen (2011) describe the engineer process a third way, similar to Eisenkraft but with a slightly different structure. These engineering design processes, despite their differences, all share one very important idea, which is that the engineering design process is a cycle. To be done properly, the engineer should design and test repeatedly until the design and model is satisfactory. This, by all accounts, can be a time consuming process. While the instructor was aware of this and planned time into this study for students to complete the engineering cycle, some groups could have benefited from have more time to plan and revise their projects.

Motivation

It was observed during the study that the students seem to enjoy the engineering challenges by evidence of their behavior, engagement and comments to the teacher. During any construction phase of the engineering process, students were overwhelming on task and engaged; off task behavior was almost nonexistent. Students reported that they preferred engineering challenges to more traditional labs “cookbook” type labs, where the procedure and

Pre and Post Test Reliability

All pre and post test questions were short answer questions graded by the author, with the aid of a rubric. Short answer questions were chosen over multiple choice or true and false questions because of their lower incidence of false positive responses. Despite the lower incidence of false positive responses, there is a greater likelihood of error on the part of the grader, especially when responses were given that did not neatly fit into the rubric. This was not a huge problem but may be a source of error.

Final Analysis

In conclusion, the incorporation of engineering practices into a biology curriculum appears to be highly successful way of teaching science content. The data collected supports that students greatly increased their understanding of homeostasis and digestion after completing the engineering challenges for those topics. The incorporation of engineering practices also appears to be a successful way to teach students about the process of engineering. The data collected shows student improvement in most of the engineering practices that were assessed on the pre and post test however, there was no significant improvement in the engineering designs or supporting their conclusions with evidence between the two engineering challenges.

On their own, the use of engineering challenges are a valid teaching strategy for teaching the practices of scientist and engineers, problem solving skills, and creativity but with the additions of students being able apply their knowledge of science content and increasing their motivation, teaching using engineering challenges is made a desirable way to teach despite the extra time needed for students to go through the design process.

Improvements

After each engineering challenge, students identified which practices of an engineer they used during that challenge. In doing so, many students treated this processes without much thought, much like checking items off of a list. It may have been beneficial to go a step further by having students reflect on their growth in each area and keep track of this over the course of the study. Much like engineers check their finished product to make sure it fits the initial goals, so should students the check their progress to make sure they achieve the goal of understanding engineering design principles.

A major limitation to engineering challenges is the added time needed to complete the design process. Quite often the process can take more than a few class periods, which means it may be difficult to do more than a few throughout the duration of a course. To overcome this obstacle, it may be beneficial to have students perform "dry" engineering challenge, in which the students would only complete the first step of the design process (Figure 1), the "sketching phase". In doing so, they could practice defining problems, identifying constraints, and design solutions, all within a relatively short amount of time and with using relatively few materials.

APPENDICES

APPENDIX A:

Parent Consent Form

Parental Consent and Student Assent Form

Dear Students and Parents/Guardians:

I would like to take this opportunity to welcome you back to school and invite you to participate in a research project, **The Incorporation of Engineering Practices into the Life Science Curriculum**, which I will conduct as a part of this Biology this Semester. My name is Mr. Stephen Potter and I am your science teacher for the first semester and I am also a master's degree student at Michigan State University. Researchers are required to provide a consent form like this to inform you about the study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

What is the purpose of this research? I have been working on effective ways to incorporate engineering practices into the life science curriculum and I plan to study the results of this teaching approach on student comprehension and retention of the material. The results of this research will contribute to teacher's understanding about the best way to teach about science topics. Completion of this research project will also help me to earn my master's degree in Michigan State University's College of Natural Science.

What will students do? Students will participate in the usual instructional curriculum for Biology A but with added engineering activities infused throughout the semester. Students will complete the usual assignments, laboratory experiments and activities, class demonstrations and pretest/posttest just as you do for any other unit of instruction. There are no unique research activities and participation in this study will not increase or decrease the amount of work that students do. I will simply make copies of student's work for research purposes. This project will take place in Fall of 2013 and continue throughout the first marking period (9 weeks). I am asking for permission from both students and parents/guardians (one parent/guardian) is sufficient) to use copies of student work for my research purposes.

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

What are the potential risks? There are no foreseeable risks associated with completing course assignments, laboratory experiments and activities, class demonstrations, and pretest/posttests. In fact, completing coursework will be very beneficial to students. Another person will store the consent forms (where you say "yes" or "no") in a locked file cabinet that will not be opened until after I have assigned the grades for this marking period. That way I will not know who agrees to participate in the research until after grades are issued. In the meantime, I will save all of the written work. Later I will analyze the written work for students who have agreed to participate in the study and whose parents /guardians have consented.

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

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

Who can you contact with questions and concerns? If you have concerns or questions about this study, please don't hesitate to contact:

Mr. Stephen Potter
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118 North Kedzie Lab
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East Lansing, MI. 48824
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517.432.2152x107

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

How should I submit this consent form? Please complete the attached form. **Both** the student and parent/guardian must sign the form. Please return with your student a form indicating interest either way. **Please return this form in a sealed envelope to Ms. Boulanger's room, E212, by January 24th, 2014**.

Parents/guardians should complete this following consent information:

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

Please check all that apply:

Data:

______ I give Stephen Potter permission to use data generated from my child's work in class for his thesis project. All data shall remain confidential.

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

Photography, audio recordings, or videotaping:

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

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

Signatures: ______________________________________ _________

(Parent Signature) **(Date)**

______________________________________ _________

(Student Signature) **(Date)**

Important

Please return this form in the sealed envelope to Ms. Boulanger's in Room E212 by January 24th, 2014.

APPENDIX B:

Biology Case Study Overview

General Story Line of the Biology Case Study:

First semester biology is centered on a case study storyline of a water borne illness. Some teachers use Giardia and a few use Cholera with similar symptoms of vomiting, diarrhea, fever, pains, and death. The beginning of the first unit starts out with scientific method review. We often start with a laboratory experiment on the first day or so and each student group chooses a variable to test in their experiments. Experimental process and terms, working in lab and writing lab reports is a main focus.

Next we dive into the main case study. There is storyline about people who have gotten ill in a certain situation and students look at hospital records, interviews from the patients and people involved, and maps of areas affected. Students investigate water samples (and/or patient bodily fluid samples) from the infected area and discover some “circles” in some places. Upon further study and walking through steps to prove whether the circles cause the illness (Koch’s Postulates), students “prove” they cause the illness and then experiment to determine what these circles are. They design experiments to see if the circles breathe, eat, excrete, grow, respond to stimuli, are made of cells or cell parts, and reproduce. They determine the circles are alive and then research what they could be (protozoan, fungi, bacteria, virus, etc). During this process students discover that viruses are not alive and that the circles are not a virus. Through this research they know they are a cell and are alive.

Next the students try to figure out how this disease affects the body, how to treat it and cure it. They do some basic body system research projects related to homeostasis and then focus in on the digestive system as a class. The first part of this unit is to do background work on nutrients in food, chemistry of molecules, enzymes and indicators. Next we focus more on the details of both anatomy and physiology of the digestive system, with several labs built in. Students discover what food type and what enzymes/environment act in each digestive system organ. Eventually they get into the absorption of the food and water through the walls of the intestine (villi) and see that this illness is affecting that process the most.

Since absorption is diffusion and osmosis, the next unit focuses on that. We are also introducing the basics of cells at this point. Students need a detailed understanding of the structure and function of the cell membrane and we also compare it to the cell wall of other organisms too. Students design and conduct a variety of diffusion and osmosis experiments as well as active transport. Treatments are discussed now that students understand the overall process.

Finally, students cure and kill the culprit of the disease; details of the cell are what wrap the case study. If we can figure out how to get into the giardia/cholera and dismantle its system of working, we could further treat and cure our patients. Students work through a series of activities to discover many of the functions of the cell organelles. Students observe micrographs of cells during protein synthesis to determine what the role of each organelle is during the protein factory analogy. There are labs and demos to get at the functions of the mitochondria, chloroplast and lysosomes as well. If time permits, teachers can also go into specialized cells and how the structure of a cell is directly related to its function.

APPENDIX C:

Engineering Pre/Post Test with Rubric

Name: ______________________________________ Date: ____________ Hour: _______

Biology

Pretest - What do Engineers do?

1. What does an engineer do?

2. ~~How many different types of engineers can you think of?~~

3. How is a scientist different from an engineer?

4. Which of the following statement(s) would most likely be said by and engineer rather than a scientist?

   a. Why can I see my breath in the winter?

   b. How can I make a car engine more powerful?

   c. Why do cars get better fuel efficiencies (miles per gallon) on the highway than they do in the city?

   Explain:

Once you go past this page,
you may not come back
to change your answers!

5. An aeronautical engineer is an engineer that designs airplanes. Why might it be important for them to develop and use models?

6. You are an engineer that is tasked with making a windmill that will capture the most energy possible from the wind.
   a. As an engineer, how might you go about figuring this out?

   b. What are some variables (things that you can change) that could make the windmill work better?

   c. Besides the amount of energy, what might be some other thing an engineer could consider to determine whether or not their design is effective or worthwhile?

7. Two engineers built two different windmills. Below is the data for how they performed at different wind speeds.

Table 8: Windmill data

Windmill A	
Wind speed (mph)	**Energy output (kW)**
2	1.5
4	3
8	6
10	7.5
12	9

Windmill B	
Wind speed (mph)	**Energy output (kW)**
1	0.5
5	2.5
9	4.5
15	7.5
20	10
22	11

8. Which of the two windmills performed better?

9. Explain why:

10. Is there any way that we could use mathematics in the previous problem to clearly show which windmill was better?

Table 9: Pre and Post Test Rubric

Question	1	2	3	4
Question 1	Incorrect or absent response	Students states only one thing an engineer does	Students states more than one of the things that engineers do but not all.	A person who designs, builds, and/or improves upon machines or systems.
Question 2	Incorrect or absent response	Student can name one type of engineer	Student can name two types of engineers	Student can name three types of engineers
Question 3	Incorrect or absent response	Student answer is partially correct.	Student answer what one of the can do but not both.	Student identifies that a scientist finds tries to find the answers to questions, Engineer design and build
Question 4	Incorrect or absent response	Student identifies correct and incorrect responses with an incorrect or missing explanation	Student identifies correct responses with incorrect or missing explanation	Student identifies correct responses with an explanation
Question 5	Incorrect or absent response	Students response is only partially correct	Student only identifies one part.	Simulate and test possible solutions to identify flaws and/or make improvements.
Question 6 a	Incorrect or absent response	Design a solution	Design and test ideas	Plan, design and test ideas using models or simulations
Question 6 b	Incorrect or absent response	Students can name one variable	Students can name two variables	Student can name three or more variables
Question 6 c	Incorrect or absent response	Students can name one variable	Students can name two variables	Student can name three or more variables

Table 9: (Cont'd)

Question 7	Incorrect or absent response	Student only in partially correctly graphs data	Student graphs data but on the wrong axis	Student graphs data correctly
Question 8 and 9	Incorrect or absent response	Student accurately picks the better performing windmill but with the incorrect explanation	Student accurately picks the better performing windmill but with partially correct	Student accurately picks the better performing windmill with the correct explanation
Question 10	Answers yes with no further explanation or absent response	Incorrect response	Student describes using an mathematical tool, but one that is not appropriate, like the average	Student describes using an appropriate mathematical tool, like finding the slope of the line

APPENDIX D:

Homeostasis Pre/Post Test with Rubric

Name: ______________________________ Date: _______________ Hour: _____________

Biology

Pre and Post Test - Homeostasis

1. What is homeostasis?

2. Provide as many examples as you can of homeostasis.

3. There are two types of feedback systems. Can you name and describe each one?

Table 10: Homeostasis Pre and Post Test Rubric

CATEGORY	1	2	3	4	5
Question #1	Incorrect or absent response	Identified it as a human function	Identified it as a function of all living things	Identified it as a function of all living things in which it is a response to the environment	Identified it as a function of all living things in which it is a response to the environment through a feedback mechanism
Question #2	Incorrect or absent response	Student could identify one process	Student could identify two processes	Student could identify three processes	Student could identify four or more processes
Question #3	Incorrect or absent response	Student could name one type of feedback system but could describe it	Student could name two types of feedback systems but could not describe them	Student could name one or two types of feedback systems but could only describe one	Students could correctly identify both types of feedback systems and correctly describe them

APPENDIX E:

Digestion Pre and Post Test with Rubric

Name: ______________________________ Date: ________________ Hour: __

Pretest - Digestion

Question: Describe what happens to a cheeseburger when you eat it.

Be sure to include:

- Every organ that aids in the digestion of the food (true and accessory)
- What happens to the food while it is in that organ (Is chemical or mechanical digestion taking place)
- What chemicals are aiding in digestion and where and what nutrients are they acting on

Your answers should be set up like this:
First Location: explanation of what happens
Second location: explanation of what happens
And so on…

Table 11: Digestion Model Rubric

CATEGORY	1	2	3	4	5
Mouth, Esophagus	Incorrect or absent response	Student listed organ(s) but not the function, digestive chemicals, or nutrients acted on	Student listed organ(s) with only one other piece of correct information between function chemicals or nutrients	Student listed organ(s) with two other piece of correct information between function chemicals or nutrients	Student correctly listed organ(s) with function, chemicals and nutrients
Stomach	Incorrect or absent response	Student listed organ but not the function, digestive chemicals, or nutrients acted on	Student listed organ with only one other piece of correct information between function chemicals or nutrients	Student listed organ with two other piece of correct information between function chemicals or nutrients	Student correctly listed organ with function, chemicals and nutrients
Liver	Incorrect or absent response	Student listed organ but not the function, digestive chemicals, or nutrients acted on	Student listed organ with only one other piece of correct information between function chemicals or nutrients	Student listed organ with two other piece of correct information between function chemicals or nutrients	Student correctly listed organ with function, chemicals and nutrients
gallbladder	Incorrect or absent response	Student listed organ but not the function, digestive chemicals, or nutrients acted on	Student listed organ with only one other piece of correct information between function chemicals or nutrients	Student listed organ with two other piece of correct information between function chemicals or nutrients	Student correctly listed organ with function, chemicals and nutrients

Table 11: (Cont'd)

Pancreas	Incorrect or absent response	Student listed organ but not the function, digestive chemicals, or nutrients acted on	Student listed organ with only one other piece of correct information between function chemicals or nutrients	Student listed organ with two other piece of correct information between function chemicals or nutrients	Student correctly listed organ with function, chemicals and nutrients
Small intestine	Incorrect or absent response	Student listed organ but not the function, digestive chemicals, or nutrients acted on	Student listed organ with only one other piece of correct information between function chemicals or nutrients	Student listed organ with two other piece of correct information between function chemicals or nutrients	Student correctly listed organ with function, chemicals and nutrients
Large intestine	Incorrect or absent response	Student listed organ but not the function, digestive chemicals, or nutrients acted on	Student listed organ with only one other piece of correct information between function chemicals or nutrients	Student listed organ with two other piece of correct information between function chemicals or nutrients	Student correctly listed organ with function, chemicals and nutrients
Rectum/anus	Incorrect or absent response	Student listed organ(s) but not the function, digestive chemicals, or nutrients acted on	Student listed organ(s) with only one other piece of correct information between function chemicals or nutrients	Student listed organ(s) with two other piece of correct information between function chemicals or nutrients	Student correctly listed organ(s) with function, chemicals and nutrients

1. Mouth –
    a. physical digestion (teeth grinds food to physically digest food)
    b. Salivary amylase(enzyme) breaks starches into glucose

2. Esophagus–
    a. (no changes happen in the esophagus) to the stomach

3. Stomach –
    a. does physical grinding
    b. stomach acid makes (activates) pepsin work
    c. Pepsin (enzyme) helps H_2O makes protein into amino acids

4. Liver makes bile , Gallbladder stores bile , Pancreas makes enzymes
    a. Liver, gallbladder and pancreas are accessory organs, no food goes through them

5. Small intestine -
    a. Bile and enzymes go through the bile duct to get to the small intestine
    b. Food goes from stomach to small intestine where bile does separates the fat– don't say that it breaks it down (it implies a chemical change)
    c. Lipase and water can break separate fats into 3 fatty acids and glycerol
    d. Trypsin and water break down protein into amino acids
    e. Pancreatic amylase and water break down starch into glucose
    f. All building blocks are absorbed through walls of small intestine into the blood.

6. large intestine –
    a. Undigested food (cellulose) goes to the large intestine and water is reabsorbed

7. Rectum/anus
    a. Undigested material is stored and released from the body

APPENDIX F:

Homeostasis Lesson Plan and Challenge

Lesson Plan

9/24/13 Lesson 1: Homeostasis

<u>Objectives</u>

State High School Content Expectations (HSCE):

B2.3 Maintaining Environmental Stability - The internal environment of living things must remain relatively constant. Many systems work together to maintain stability. Stability is challenged by changing physical, chemical, and environmental conditions as well as the presence of disease agents.

- B2.3B - Describe how the maintenance of a relatively stable internal environment is required for the continuation of life.
- B2.3C - Explain how stability is challenged by changing physical, chemical, and environmental conditions as well as the presence of disease agents.

B2.3x Homeostasis - The internal environment of living things must remain relatively constant. Many systems work together to maintain homeostasis. When homeostasis is lost, death occurs.

- **B2.3e Describe how human body systems maintain relatively constant internal conditions (temperature, acidity, and blood sugar).**
- B2.3f Explain how human organ systems help maintain human health.

Next Generation Science Standards (NGSS):

- HS-LS1-3 – Plan and conduction an investigation to provide evidence that, feedback mechanisms maintain homeostasis.

Engineering Concepts:

- Design and carryout investigations
- Analyzing and interpreting data
- Engaging in arguments from evidence
- Obtaining, evaluating, and communicating information.

Lesson:

(Pertinent background information: Students have been working on a case study, investigating a group of campers that have fallen sick)

Pre-instruction

1. Students are given a pretest on homeostasis

Introduction

1. Students are asked to brainstorm what could be causing our campers to be sick.
2. Students are asked to define what does it means to "be sick" and to explain how someone could get so sick that they could die.
3. Students are asked to brainstorm ways that you could test for someone being sick.

Instruction

1. Teacher defines homeostasis.
2. The class comes up with examples they can think of, followed by the teacher giving some examples.
3. Teacher defines and explains feedback mechanisms.

Engineering Challenge (two days):

Day one:

1. Students are told that they need to find a way to test for and measure that living things undergo homeostasis and then support it with the evidence that they gathered.
2. Students brainstorm ways that they could test for homeostasis
3. Students design and plan their investigation.

Day two:

1. Students carry out their experiments and determine whether or not they were successful using their data as evidence

Assessment:

1. Students assessed on their abilities to plan and carry out an investigation
2. Students assessed on their abilities to support their argument from evidence

Notes:

- Students struggle with brainstorming ideas
- **Students have a hard time picking out the evidence for homeostasis.** Many students want to pick the change that is happening in the body, rather than the body's response to keep it the same.
- Only a limited number of options for this experiment that doesn't involve blood. Heart rate and the body's response to temperature change were the only two tests that were feasible.

Name: ______________________________ Date: _______________ Hour: ____

Biology

Engineering Challenge: Homeostasis

Objective

- Design an experiment to show that living things undergo homeostasis

Brainstorm

1. What is homeostasis?

2. What are some examples of homeostasis that we used in class?

3. With your group, brainstorm some ideas of how you could test for homeostasis. Write some of your ideas below.

Identify the requirements of your experiment

1. What are you going to be testing?

2. What environmental condition will you be changing?

3. What observations and measurements will you be taking? (You should have at least three different things to observes and/or measure, unless it is not possible for your experiment)

4. How will you keep track of your observations and data?

5. How will you present your data that you have collected?

Investigation:

Specified Requirement of investigation (for this investigation, it's not the hypothesis but the objective)**:**

Materials (a list of everything you need)**:**

Procedure (exact instructions for your lab)**:**

Observations and Data (observations should be a list, data should be in tables)**:**

Analysis (a graph should be constructed of your data, the space below should be an explanation of your graph)**:**

Conclusion (were you successful with the objective for this engineering activity; explain using evidence from your experiment)**:**

Post-lab questions:

1. List the changes you observed in your experiment.

2. Explain how the changes help the body adjust to maintain equilibrium (homeostasis)?

3. Does your experiment show any evidence of a feedback mechanism? If so, is it a positive of a negative feedback system?

4. In this experiment, did you participate in any engineering practices? If so what were they?

Table 12: Homeostasis Grading and Rubric

Lab Section	Comments	Score
Brainstorming: Did you come up with multiple ideas with your group?		/2
Identifying the requirements of the experiment: Did you identify all necessary parts before the experiment?		/2
Experiment: See rubric below		/10

CATEGORY	2	1	0
Brainstorming	Multiple, relevant tests were thought up	Few or inappropriate tests were thought up	No relevant tests were thought of.
Identifying the requirements of the experiment	All requirements clearly identified.	Only some requirements clearly identified.	Few or no requirements clearly identified.

Table 12: (Cont'd)

CATEGORY	2	1	0
Experimental Design	Experimental design is a well-constructed test of the stated problem.	Experimental design is adequate to test the hypothesis, but leaves some unanswered questions.	Experimental design is not adequate to test the hypothesis.
Materials/ Procedures	All materials are listed with a description of setup. Procedures are listed in clear steps. Each step is numbered and is a complete sentence.	Some materials are missing or setup is not complete Procedures are lacking clarity or completeness.	Most of the materials and/or setup used in the experiment are missing. Procedures are listed but are not in a logical order or are difficult to follow
Data/Observations	Professional looking and accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled..	Accurate representation of the data in tables and/or graphs but with missing labels and titles. or Accurate representation of the data in written form, but no graphs or tables are presented	Data and observations are not represented in a logical way
Analysis	The relationship between the variables is discussed and trends/patterns logically analyzed.	The relationship between the variables is discussed but trends/patterns are incorrectly analyzed.	The relationship between the variables is discussed but no patterns, trends or predictions are made based on the data.

Table 12: (Cont'd)

Conclusion	The experiment was able to achieve the objective. Evidence for this is shown.	The experiment was able to achieve the objective. No evidence for this is shown.	The experiment was able to achieve the objective. No evidence for this is shown.

APPENDIX G:

What Food Does our Pathogen Prefer Lesson Plans and Challenge

Lesson Plan

10/10/13 Lesson 2: What Food Does Our Pathogen Prefer?

Objectives

State High School Content Expectations (HSCE):

B2.5 Living Organism Composition - Carbohydrates and lipids contain many carbon-hydrogen bonds that also store energy.

- **B2.5D Describe how individual cells break down energy-rich molecules to provide energy for cell functions.**

Next Generation Science Standards (NGSS):

- HS-LS1-7 – Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy. (Emphasis of this concept is the understanding of the inputs and outputs involved in cellular respiration)

Engineering Concepts:

- Design and carryout investigations
- Analyzing and interpreting data
- Engaging in arguments from evidence
- Obtaining, evaluating, and communicating information.

Lesson:

(Pertinent background information: Students have been working on a case study, investigating a group of campers that have fallen sick. They have found an unknown pathogen and through the use of Koch's Postulates and the Alive Labs and have determined that it is a living organism)

Introduction

1. Students are asked to list the reasons (the 7characteristics of living things that we learned in class) that we know our pathogen is alive. Eating or taking in energy is highlighted as a specific characteristic that we will be testing.
2. The teacher suggests that a possible cure or treatment for the disease maybe to find what it likes to eat and what it doesn't.
3. Students are asked to brainstorm ways that you could test which food (sugar) our pathogen prefers.
4. Students are given some ideas from the teacher and shown equipment that they can use.

Engineering Challenge (two days):

Day one:

1. Students are asked to brainstorm ways that you could test which food (sugar) our

pathogen prefers.
2. Students design and plan their investigation.

Day two:
1. Students carry out their experiments and determine whether or not they were successful using their data as evidence

Assessment:
1. Students assessed on their abilities to plan and carry out an investigation
2. Students assessed on their abilities to support their argument from evidence

Notes:

- Students struggle with graphing their data
- Students struggle with supporting their evidence with data.

Name: ________________________________ Date: ______________ Hour: _________

Biology

Engineering Challenge: What food does our "pathogen" prefer?

Objective

- Design an experiment to show what type of sugar our "pathogen" prefers?
- Identify which of the eight engineering practices we are using.

There are four different types of sugar that we will be testing: <u>glucose (blood sugar), sucrose (table sugar), fructose (fruit sugar), and lactose (milk sugar)</u>. Your job is to plan and carry out an investigation to show which sugar the "pathogen" likes best. We do not have a very accurate test for measuring how much of a particular sugar is being eaten so we will have to measure a different characteristic of life other than "eats".

(Hint: What characteristic of life will change the quickest when an organism becomes more active?)

Brainstorm

1. What characteristic of life should we test for?

2. What ways have we tested for this characteristic of life in class?

3. Brainstorm with your group about ways we could test for this characteristic of life? Draw picture of your setup below:

4. How will you keep track of your observations and data throughout this experiment?

5. How will you present your data that you have collected?

Investigation:

Specified Requirement of investigation (for this investigation, it's not the hypothesis but the objective)**:**

Materials (a list of everything you need)**:**

Procedure (exact instructions for your lab)**:**

Observations and Data (observations should be a list, data should be in tables)**:**

Analysis (a graph should be constructed of your data, the space below should be an explanation of your graph)**:**

Conclusion (Were you successful with the objective for this engineering activity; explain using evidence from your experiment)**:**

Post-lab questions:

5. Below are the practices of engineers. Next to each, respond whether we engaged in that practice or not. If we did engage in that practice, give an example how.

    - Asking questions and defining problems

    - Developing and using models

    - Planning and carrying out investigations

    - Analyzing and interpreting data

    - Using math and computational thinking

    - Constructing explanations and designing solutions

    - Engaging in argument from evidence

    - Obtaining, evaluating, and communicating information

Table 13: Digestion Model Rubric

Lab Section	Comments	Score
Brainstorming: Did you come up with multiple ideas with your group?		/2
Identifying the requirements of the experiment: Did you identify all necessary parts before the experiment?		/2
Experiment: See rubric below		/10

CATEGORY	2	1	0
Brainstorming	Multiple, relevant tests were thought up	Few or inappropriate tests were thought up	No relevant tests were thought of.
Identifying the requirements of the experiment	All requirements clearly identified.	Only some requirements clearly identified.	Few or no requirements clearly identified.

CATEGORY	2	1	0
Experimental Design	Experimental design is a well-constructed test of the stated problem.	Experimental design is adequate to test the hypothesis, but leaves some unanswered questions.	Experimental design is not adequate to test the hypothesis.
Materials/ Procedures	All materials are listed with a description of setup. Procedures are listed in clear steps. Each step is numbered and is a complete sentence.	Some materials are missing or setup is not complete Procedures are lacking clarity or completeness.	Most of the materials and/or setup used in the experiment are missing. Procedures are listed but are not in a logical order or are difficult to follow
Data/Observations	Professional looking and accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled..	Accurate representation of the data in tables and/or graphs but with missing labels and titles. or Accurate representation of the data in written form, but no graphs or tables are presented	Data and observations are not represented in a logical way

Table 13: (Cont'd)

Analysis	The relationship between the variables is discussed and trends/patterns logically analyzed.	The relationship between the variables is discussed but trends/patterns are incorrectly analyzed.	The relationship between the variables is discussed but no patterns, trends or predictions are made based on the data.
Conclusion	The experiment was able to achieve the objective. Evidence for this is shown.	The experiment was able to achieve the objective. No evidence for this is shown.	The experiment was able to achieve the objective. No evidence for this is shown.

APPENDIX H:

Clean the Water

Lesson Plan

10/23/13 Lesson 3: Clean the Water

Objectives
State High School Content Expectations (HSCE):

- B1.1C - Conduct scientific investigations using appropriate tools and techniques (e.g., selecting an instrument that measures the desired quantity—length, volume, weight, time interval, temperature—with the appropriate level of precision).

- B1.2g - Identify scientific tradeoffs in design decisions and choose among alternative solutions.

Next Generation Science Standards (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 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.

Engineering Concepts:

- Design a solution.

Lesson:
(Pertinent background information: Students have been working on a case study, investigating a group of campers that have fallen sick. They have found an unknown pathogen and through the use of Koch's Postulates and the Alive Labs and have determined that it is a living organism. The students have identified the organism as giardia.)

Introduction

1. Students learn about how in some places in the world, water-borne diseases are big problem and kill millions of people each year. They are asked to design a solution to this complex real-world problem by designing a water purification device.
2. Students are given some ideas from the teacher and shown equipment and materials that they can use.

Engineering Challenge (two days):

Day one:

1. Students are asked to brainstorm ways that you could design an inexpensive water purification device.
2. Students are given time in the computer lab to research ideas.
3. Students design and plan their investigation.
4. Students that are struggling will be shown the following websites to get ideas:
   -Link: http://mrpotterscience.weebly.com/uploads/1/2/8/8/12886652/nr_wq_2012-6.pdf
   -Link: http://cleardomesolar.com/solarpurewaterstill.html
   -Link: http://www.envirogadget.com/water-saving/evaporation-based-water-purifier-cone/

Day two:

1. Students experiment, test, and redesign their water purification devices until they are successful in cleaning the water of “pathogens” (yeast)
Assessment: 1. Students assessed on their plan and construct a working water purifier.
Notes: ➢ Students struggle coming up with unique ideas without any help. ➢ There were a lot of “copycats”. Once one group figured out a way to do it, other groups quickly followed. ➢ Putting “cost constraints” on different materials would keep projects small and therefore less mess as well as het at another part of the NGSS standard

Name: ____ Date: ________________________ Hour: ___________________
Biology

Engineering Challenge: Clean the water

Objective

- Design a procedure or apparatus for cleaning and purifying our “dirty” water?
- Identify which of the eight engineering practices we are using.

Research

In the space below, write down some ideas that you found during your research.

Design

In the space below, explain in words and draw a picture of your purifying device.

Test Results

In the space below, explain whether or not you were successful.

APPENDIX I:

Model of the Digestive System

Lesson Plan

11/8/13 Lesson 3: Design a Model of the Digestive System

<u>Objectives</u>
State High School Content Expectations (HSCE):

- B2.2C - Describe the composition of the four major categories of organic molecules (carbohydrates, lipids, proteins, and nucleic acids).
- B2.2D - Explain the general structure and primary functions of the major complex organic molecules that compose living organisms.
- B2.2f - Explain the role of enzymes and other proteins in biochemical functions (e.g., digestive enzymes).
- B2.3d - Identify the general functions of the major systems of the human body (digestion)

Next Generation Science Standards (NGSS):
- HS-LS1-2 – Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multi-cellular organisms.

Engineering Concepts:
- Developing and using models.

Lesson:
(Pertinent background information: Students have been working on a case study, investigating a group of campers that have fallen sick. They have found an unknown pathogen and through the use of Koch's Postulates and the Alive Labs and have determined that it is a living organism. The students have identified the organism as giardia and that it specifically attacks the digestive system. To find a possible treatment for the disease, we need to understand what it is doing to the digestive and how the digestive system works)

Introduction
1. Students are asked hypothesize about which body system giardia is likely affecting. All of the symptoms relate to the digestive system and that is identified as the organ system that is likely affected.
2. Students hypothesize about how giardia affects the digestive system and how it causes the symptoms it does. Leads us to learn about the digestive system

Instruction
1. Students are taught the structure and function of the digestive system through a series lectures (short Power Points), labs, and hands-on activities.
2. Students are taught the structure and function of enzymes and macro molecules through a series lectures (short Power Points), labs, and hands-on activities.

Engineering Challenge (multiple days):
Day one:
1. Students are challenged to represent all the information we have learned about digestion, enzymes and macromolecules in one 2D or 3D model.
2. Students are given time brainstorm and come up with ideas.
3. Students design and plan their model.

Day two and beyond:

1. Students are given time to in class to work on their models.
Assessment: 1. Students were assessed on the inclusion and accurate representation of all of the items from the rubric.
Notes: ➢ Students were encouraged to do something besides a poster but only two groups did. ➢ Students did will with the structure and function of the organs but not as well on the enzymes and nutrients.

Name: ____ Date: ______________________ Hour: _________________

Biology

Engineering a Model of the Digestive System

Project task: Make a model of the digestive system. Your model can be a 2 or 3 dimensional representation and must include the following things:

Your model should include:

- All digestive organs
- All digestive chemicals
- All of the nutrients (polymers) and what and where they are broken down, and what they are broken down into (Monomers)

What I will be looking for:

1. Mouth (1) –
   a. physical digestion (teeth grinds food to physically digest food) (1)
   b. Salivary amylase(enzyme) breaks starches into glucose (1)

2. Esophagus (1) –
   a. (no changes happen in the esophagus) to the stomach (1)

3. Stomach (1) –
   a. does physical grinding (1)
   b. stomach acid makes (activates) pepsin work (1)
   c. Pepsin (enzyme) helps H_2O make protein into amino acids (1)

4. Liver makes bile (1), Gallbladder stores bile (1), Pancreas makes enzymes (1)
   a. Liver, gallbladder and pancreas are accessory organs, no food goes through them (1)

5. Small intestine (1) -
   a. Bile and enzymes go through the bile duct to get to the small intestine (1)
   b. Food goes from stomach to small intestine where bile does separates the fat– don't say/show that it breaks it down (it implies a chemical change) (1)
   c. Pancreatiatin (mix of three enzymes) and water break down all polymers into monomers (2)
   d. All building blocks are absorbed through walls of small intestine into the blood. (1)

6. large intestine (1) –
   a. Undigested food (cellulose) goes to the large intestine and water is reabsorbed (1)

7. Rectum/anus (1)
   a. Undigested material is stored and released from the body (1

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