

# An Algae-Based Curriculum for Globally Conscious Engineering Education

Kauser Jahan<sup>1</sup>, Gina Tang<sup>2</sup>, Roisin Breen<sup>3</sup>, Patricia Hurley<sup>1</sup>, Megan Mittenzwei<sup>1</sup> and Dennis Boileau<sup>1</sup>, Nathan C. Lamb<sup>2</sup>, Gena Leigh Gizzi<sup>2</sup>, Kevin Trinh<sup>2</sup> and Edward C. Yates<sup>2</sup>

<sup>1</sup>Civil Engineering; <sup>2</sup>Electrical and Computer Engineering; <sup>3</sup>Chemical Engineering Rowan University, USA

## Abstract

*An algae-based curriculum is being used to teach engineering fundamentals and concepts from the humanities such as ethics, gender and racial biases, discrimination, and public policy. The project involves hands on experiments with algae that relate to core concepts in engineering such as materials, energy, fluid mechanics, thermodynamics, water treatment, and green engineering. Each experiment requires data collection, analyses, and interpretation. Technical and reflective writings along with oral presentations are integrated with the course. Students are exposed to case studies through movies, readings, and documentaries that allow them to learn about ethics, race and gender issues, and public policy. The experiments of the curriculum give students the fundamental skills and knowledge necessary to tackle some of the world's most challenging issues and encourage interest in solving them. They also give students a broad knowledge base of humanities and global issues that are commonly not included in typical engineering courses.*

## 1. Introduction

Algae is widely recognized as a photosynthetic organism that is ubiquitous. However, it is rare that that K-12, science and engineering students make a connection to the prospect of this microbe playing a significant role in impacting the future of this world. This project focuses on introducing students and K-12 educators to the NAE Grand Challenges of the 21st Century through the use of algae [1].

Through this curriculum, students are engaged in the scientific discovery process using both exciting hands-on activities and cyber-learning experiences that introduce them to core engineering fundamentals, such as mass and energy balances; material properties; fluid flow; work, energy, and efficiency; water quality and treatment; unit physical, chemical and biological processes; microbiology; power and electrical signal processing. The algae theme also adds the need for an understanding of biological systems, ecosystems, pollution, alternate energy and sustainable development. A strong, unique focus of

this project is in combining critical reflection through activities that invest in the humanities through literary readings, movies, documentaries, video clips on social and environmental injustices, and public policy.

## 2. Algae Grows the Future

Algae Grows the Future is the name of a team comprised of junior and senior college students that is focused on creating an algae-based curriculum for K-12 and college students. The project is funded by the National Science Foundation (NSF) and was created in partnership with the Center for Aquatic Sciences (CAS) at the Adventure Aquarium. The theme of algae was selected because of the wide range of applications of algae, ease of growth and maintenance, and accessibility to any classroom. The Algae Grows the Future team aims to promote a high-quality engineering education, along with the integration of humanities to improve students' understanding of the connections between the two fields.

### 2.1. Globally Conscious Learning

The promotion of global consciousness among students was a primary focus in the creation of this curriculum. The experiments and activities were designed not only to teach students principles of engineering and experimentation, but also to encourage the consideration of world needs and to exemplify how engineering and science can be applied to meeting these needs. In today's world, issues including global warming, world hunger, and energy must be addressed, and it is important that the next generation of creators are prepared and excited to tackle these issues.

STEM education is becoming increasingly prominent in classrooms with more funding and recognition. This trend is promising, especially for a future of a more diversified and prepared engineering community. Engineering provides a unique platform to make an impact on the world, as an engineer's work spans from brainstorming solutions and conducting

research to hands-on implementation and building. The products and processes that engineers develop have an impact on consumers and the environment that surrounds them, both small and large. Thus, it is vital that engineers have a global perspective. It is important to consider economics and efficiency, but the scope of engineering projects extends beyond cost and industry. Engineers must recognize the effects that their projects will have on culture, humanity, and the environment. Furthermore, it is important for the field of engineering to address global issues, including world hunger, dependency on fossil fuels, limited access to proper healthcare, global warming, and much more.

## 2.2. Why Algae?

Algae are easy to grow and have essential lipids and protein. As shown in Figure 1, the uses of algae include biofuels, carbon sequestration, nutrient removal in wastewater, food for humans, the aquatic industry, and the nutraceutical industry. Algae-based gels are also being used in materials, medical applications and the cosmetics industry. Specifically, the *Chlorella Vulgaris* strain was used for this project due to its accessibility and ease of growth.

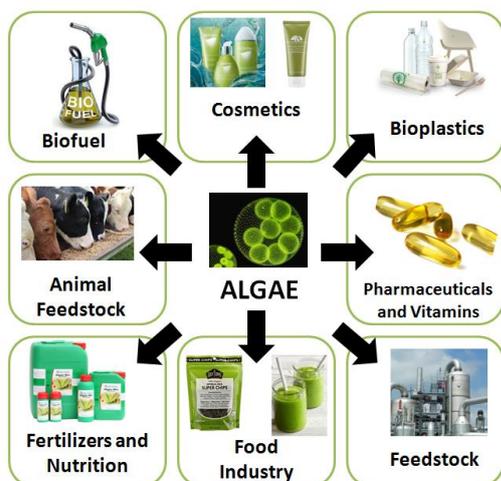


Figure 1. Algae Applications

## 3. Objectives

It is important that engineering and the humanities are delivered to students in an interwoven manner, which is a primary objective of this project. The educational goals of the algae-based curriculum are to bridge the gap between engineering and the humanities, establish social relevance to technical projects, increase participations of underrepresented students, and develop scalable, cost-effective curricular materials.

## 4. Experiments

The experiments designed for this project use algae as a central theme to expose students and educators to various science and engineering fundamentals. While everyone recognizes algae as a photosynthetic organism that is ubiquitous, it is rare that we make a connection to the prospect of this microbe playing a significant role in impacting the future of this world. The experiments enforce data collection, data analyses using statistics and Excel, and data interpretation. Each hands-on experiment is related to social and ethical issues.

### 4.1. Calorimetry

Through the process of calorimetry, the number of calories in a food sample can be determined by measuring energy exchange between a system and its surroundings. Students conduct the calorimetry experiment utilizing an empty, clean soda can as a calorimeter. The soda can is secured on a ring stand and filled with water of a known initial temperature. A food sample is lit on fire with a match and placed beneath the soda can. The final water temperature is measured after the food sample is completely burned. The energy transferred from the burning food to the water is equal to the mass of water multiplied by the specific heat of water multiplied by the change in temperature. The energy calculated is the energy of the food, often referred to as calories.

Students will test several food samples, at least one of these foods being algae-based. For example, there are algae-based chips and nutritional bars. The students will be able to compare the energy content of the food samples, along with their nutritional values, and analyze the nutritional benefits of algae. Students will be prompted to consider the benefits and potential problems associated with using algae as a source of nutrition and will learn about the pressing issue of world hunger.

### 4.2. Coagulations and Flocculation

This experiment offers a hands-on approach for students to learn about the importance of water treatment and exposes students to potential uses of algae in underdeveloped countries for water treatment. Coagulation and flocculation is the process of using chemicals to clump together and settle out particles in water, typically used at water treatment plants to remove turbidity and sanitize water. The typical coagulant utilized for this experiment is alum, as it is relatively cheap and works well to clump particles together.

Algae is often one of the lead causes of turbidity in water, since algae is typically distributed evenly throughout water and do not settle out on their own.

With the addition of different concentrations of alum to jars containing the same concentration of algae, the optimal dosage of alum needed to coagulate and flocculate the algae within the water samples can be determined. Students will practice graphing and analyzing data and working with spreadsheets.

### 4.3. Cosmetics

In 2011, Women's Health Journal stated that mineral oil hydrocarbons are one of the leading contaminants to the human body [2]. Many cosmetics products contain these hydrocarbons, along with petroleum and questionable chemicals, which are not safe or appealing to conscious customers. By finding substitutes for these ingredients, healthier cosmetic products can be created, and the use of nonrenewable resources can be reduced.

In this experiment, students will study and create a common cosmetic product - lip gloss. Lip gloss contains oil, which acts as an emollient to moisturize and soften skin. Students will learn the main components of lip gloss and what purpose each component serves. Then, students make their own lip gloss using algae oil, beeswax, honey, coloring, and essential oil for scent. This experiment is engaging and exciting for students, as they will be creating a product that they can personalize and bring home to family and friends. Students will be prompted to consider the source of ingredients in everyday products and how the products may be engineered to be safer and environmentally-friendly.

### 4.4. The Effect of Alternating Colored Lights on Algae Growth Rate

The negative effects of fossil fuels and shortages of its supply have urged the research and implementation of alternative fuel sources. In order to be a feasible alternative, a fuel source must be environmentally-friendly and economically comparable to existing fuel sources and provide net energy gain [3]. Oil extracted from algae is a desirable feedstock for biofuels, as it can be produced in controlled settings and does not compromise resources needed for other purposes. Since a high volume of fuel is required for transportation, electricity, and other societal functionings, it is vital to have access to a large supply of fuel. Therefore, in order for algae oil to be a feasible alternative to fossil fuels, algae must be able to be grown efficiently and quickly.

Studies suggest that a light source with alternating wavelength better stimulates photosynthesis in comparison to a constant wavelength [4]. In this experiment, students will learn about the photosynthetic nature of algae, physics of colored light, and will study the effect of alternating colored

lights on algae growth rate. An example of an alternating colored light set up is shown in Figure 2.



Figure 2. Alternating Colored Light Set Up

Through data analysis, students will determine the optimal light condition for a high algae growth rate. Students will be prompted to consider the prospect of algae as a biofuel and how algae can be grown on an industrial scale.

### 4.5. Photosynthesis

In order to understand the relationship between oxygen and carbon dioxide in a biological system, a fundamental understanding of the photosynthetic process is necessary. Figure 3 depicts the photosynthetic process [5].

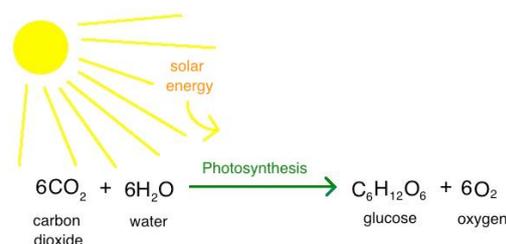


Figure 3. Photosynthetic Process

This experiment is simple, but effective. It will introduce students to the biological concepts behind photosynthesis and the differentiation between light-independent and light-dependent parts of photosynthesis. A sample of algae will be subjected to a light source and the increase in dissolved oxygen will be measured with a dissolved oxygen meter. An increase in dissolved oxygen concentration signifies that the algae is undergoing photosynthesis. After a set amount of time, the algae sample will be placed such that it will not be subjected to any light. Again, the dissolved oxygen will be measured. This procedure will be repeated, and students will analyze the reliance that photosynthesis has on the presence of

light.

#### 4.6. The Effect of Light Intensity on Oxygen Production

Similar to the photosynthesis lab described above, this light intensity experiment details how the photosynthetic nature of algae can be used to convert carbon dioxide into oxygen. However, while the photosynthesis experiment focuses solely on the presence of light, this experiment studies the relationship between light intensity, oxygen production, and culture thickness. These variables are important when considering the implementation of algae-based carbon sequestration systems in enclosed areas, where these factors can vary.

This experiment was designed to be done virtually, which will expose students to the use of spreadsheets and data interpretation. Given equations that relate light intensity, area exposed to light, culture thickness, and oxygen production, students will construct a spreadsheet that will relate the factors. Then, students will be able to determine how changing a factor, increasing culture thickness for example, may impact photosynthesis. It should be observed that increasing the thickness of an algae culture decreases oxygen production and that increasing light intensity increases oxygen production. To simplify this experiment for younger students, a preconstructed spreadsheet may be provided to students.

#### 4.7. Microtox

Algae grows naturally in bodies of water and is often undesirable in pools and ponds. It can be removed with algaecides, which not only kill algae cells, but may also inhibit the lives of other organisms in the treated area. For example, storm water may cause overflow in a pond treated with algaecides. The overflow may carry harmful chemicals from the pond to plants in the surrounding area and cause harm. In this experiment, a Microtox 500 Analyzer from Modern Water, shown in Figure 4, is used to test the effects of common algaecides on bacteria. The Microtox machine utilizes the bioluminescence of cryogenically frozen bacteria to show the toxicity of aqueous substances by taking a baseline bioluminescence reading of the bacteria, then another reading when the substance is introduced to the bacteria. Microtox readings can determine the percentage removal of the bacteria, or the fraction of the bacteria that the substance has killed. This experiment is intended for a freshman clinic setting in which students will test several algaecides and determine the lethal dose of each. Students will observe how certain chemicals influence cells and will consider how ecosystems can be affected by treatments like algaecides.

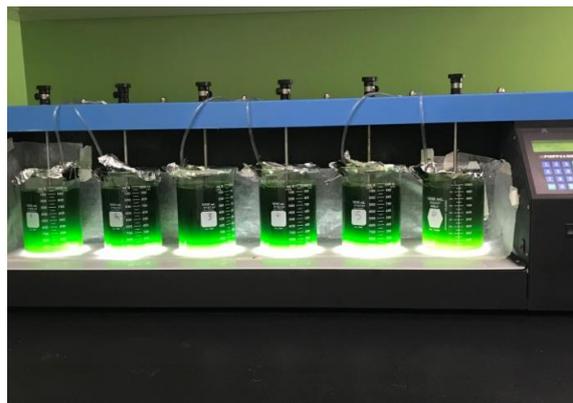


Figure 4. Microtox Apparatus

### 5. Algae City Game

An educational computer game called Algae City is being developed to provide a fun and interactive media for student to learn about algae and its many applications. The game is being developed through the Unity Game Engine and is designed specifically for middle school students. The game's storyline revolves around the idea of the player introducing algae into a modern metropolitan area as a solution for its heavy pollution and depletion of natural resources. There are four main modules –water purification, production and growth, transportation, and cosmetics. Included in the modules are five mini-games, including materials and surfboards, pharmaceutical gels, batteries, food and nutrition, and animal feed.

The game follows a linear storyline, beginning with water purification systems. The player starts with a pressing problem that has overwhelmed the city: the lake in the park and the entire water supply of the city is completely polluted. In order to restore the lake to a pristine blue, the player will work through a series of puzzles involving pipes. This level acts as an introduction and tutorial to the mechanics and complexity of the pipe systems. After this introduction, the player will move on to solve a large pipe system puzzle. In order to provide the player a refreshing change and as an educational opportunity, a short retro-style game is implemented included in the puzzle. This game simulates the algae “eating” the Carbon-dioxide and Nitrogen within the polluted water, a fun spin on the mechanisms behind carbon sequestration.

Next, the player will begin the algae production and growth module. Since the small bit of algae the player started the game with was used to purify water in the previous module, more algae must be grown to continue improving the city. The player is given an algae reactor and is in control of setting a variety of parameters, including reactor temperature, pH, salinity, and light intensity. These values can be set

via various knobs on machines in the reactor room. The player will get a score and feedback based upon which parameters were correct. The information will teach students how environmental variables impact the growth rate of algae, and students will be rewarded with the satisfaction of growing a thriving stock of algae. Students will return to this module throughout the game to maintain their algae rank, which is determined by the quantity of healthy algae in stock.

After learning how algae is grown and its potential uses, students will have the option to move on to the transportation module or cosmetics module. Transportation is vital to a city, but fuel emissions can pollute the air and water. The transportation module tasks the user in driving a public bus around the city using algae ethanol fuel instead of typical fuel. The negative effects of fossil fuels and shortages of its supply have urged the research and implementation of alternative fuel sources. While algae oil is an up-and-coming biofuels, the major negative of this fuel is the high expense. The player will therefore get the options to mix quantities of algae fuel and traditional fuel in order to limit expense and environmental impact. After the fuel blend is chosen, the player drives around the city to various bus stops, pick up passengers, and collect fares. The player is scored based upon the cost and algae composition of their fuel.

The player can also access the cosmetics module, which includes a series of mini-modules and games that explain how oil is extracted from algae and can be used in a variety of industries, including the cosmetics industry. A makeup store was created as the environment for this module to take place. An extraction machine within the store mimics those commonly found in the real world. This machine takes algae and separates it into oil, water, and biomass to be used in the creation of cosmetics. A series of mini games are used to highlight each step of this extraction process. The first step is setting the appropriate pH of the solution by collecting carbon dioxide and avoiding the hydroxide. The second step is using electromagnetic fields to split the algae into biomass, water, and oil using quantum fracturing. The third and final step is to sort the components into their respective containers as they fall from a tube above. The final game of this module is a fun game that lets the user make-over the algae character using the cosmetics created from the various types of algae. Now that the player has learned about different types of algae and what the benefits are, the player now gets the opportunity to actually see the effects. The player gets to apply the makeup to the algae characters face and wipe it off to see the effects that it has on the algae character. Upon completion of this fun mini game, the player has successfully finished the makeup module.

The store-front environment includes additional mini-games. For example, in a pharmaceutical gel game, a pet will get a cut and start lightly bleeding.

The player is tasked with applying some algae-based gel to the dog in order to make the dog feel better. Small and fun-centered games are the focus of the storefront.

At any point throughout the game, the player can return to the previous modules. Each module is accessible by returning to the place on the map in which the module was first accessed. This allows for players to get higher ranks in the main modules in order to unlock more mini-modules or allows for players to replay their favorite moments of the game. This allows the players to keep returning to the game without being bogged down by the parts that were less enjoyable.

As Algae City is currently in development, there has been limited evaluation of the game. All past and current evaluation has been restricted to the opinions of the game developers, clients, and few younger test subjects who have played parts of the game. There are future plans of game evaluation which entail creating small demo packages of specific modules and deploying the demo to local schools. The students' reactions, progress, and feedback will be recorded and after analyzing the data, the game will be adjusted accordingly. The game will also be enabled to take analytics from the player including time per level and time between inputs. Using this data, certain variables about the players experience can be determined. For example, if the length of completion is much longer than the expected length, the player most likely struggled through the game. Written quizzes or similar would be given to the test subjects after the completion of the game in order to test how much they learned about the topics presented in the game and the success of the games educational goals.

An important aspect of learning that is integrated into the game is a supplemental feedback system. To ensure that the player stays motivated to continue progressing through the entirety of the game, a ranking and reward systems were implemented. The player receives a rank based on their performance on each of the main modules. The ranking system is defined by a rank of 1 star to 5 stars with each star meaning better performance. A rank of 3 stars is necessary to continue progress throughout the game, but a higher rank would result the ability to unlock additional mini-games.

Throughout Algae City, the player is introduced to various topics related to Environmental Science and Chemistry. This is demonstrated through the players exposure to algae growth, water purification, biofuel production, and algae decomposition. The game starts with a Cutscene that is meant to immerse the player into the 3D environment and the role of the character. The Cutscene provokes emotion by going through scenes of a little child coughs due to the smog in the city and fish struggle in the pond due to the excessive water pollution. These Cutscene are meant to draw emotion and a sense of resolve from the player to

complete each module and complete the end goal of improving the city.

In addition to these Cutscenes, a cartoon algae character will be included in order to create a more welcoming and personalized game environment. The design of this character was thought out specifically to evoke certain connections and thoughts. First, the character has no features that would identify the character as either male or female in order to appeal to both demographics. The character will be voiced by a female; however, the voice clips will be altered in order to evoke a gender-neutral character. Secondly, the algae character was given a look untraditional to that of the stereotypical engineer or scientist. This choice will make students realize that anyone can be a scientist or engineer, not just those who fit into a certain box. The character will double as a guide that will provide the player with important information about how to play the game as well as giving them guidance when necessary.

In each module found in Algae City, the player is introduced to the scientific principles of each module's topic, and is repeatedly exposed to the same principles for a deeper reinforcement of the core concepts. The progression in Algae City is meant to keep the user engaged and interested in the story as they continue through the game. Throughout the game, algae is first introduced as a potential solution to the various problems in today's world, and as the game progresses, the player is exposed to how algae can be easily cultivated and learns about various uses of algae. By playing Algae City, the player becomes immersed in this virtual world and gets a firsthand experience of learning and using algae to fix real world problems, which is a unique learning experience that cannot be gained through traditional classroom learning.

## 6. Integration of Global Consciousness

### 6.1. Semester Project

The students will be placed in small groups and be assigned a country. The teams research issues that their country is facing and consider how algae can help "Grow the Future" of the country. The identify challenges – both scientific and social – that can deter or promote the use of algae. This exercise allows students to study geographical, cultural, religious, and social issues along with the government and its public policy. Teams also explore the history of the country.

Teams will be present their algae solutions for the country and are asked to write reflective reports throughout the curriculum. Strong communication skills are a necessity in the field of engineering to share statistics, data, experimental findings, and technical information. Furthermore, it is important for engineers to be able to successfully communicate with

other people in other fields of study, including the humanities. A globally conscious engineer that is unable to effectively articulate the humanitarian and environmental implications of projects will not be able to induce change. It is suggested that each experiment is followed by a written report and that reflective essays are assigned occasionally to ensure that students are making a connection between the technical experiments their humanitarian aspects.

### 6.2. Supplementary Material

The students are also assigned readings, movies, videos that expose them to social and cultural issues. For example, teams watch movies such as *Erin Brokovich*, *A Civil Action*, *The Bhopal Express*, *The Whale Rider*, *The Hidden Figures*, *The Wind Rises* and *A Rabbit Proof Fence*. The instructor can lead a discussion and analyze the movie with students to identify the issue, the consequences of the issue, and how the issue could have been prevented. Small groups of students will present on their acquired knowledge on racial and social injustices and gender biases. The teams are also exposed to gender biases and ethics in STEM fields by learning about Rosalind Franklin, Henrietta Lacks and Stephanie Kwolek.

### 6.3. Public Speaking

Oral and written communication skills are incorporated into the curriculum through technical reports, oral-presentations, and reflective essays. Strong communication skills are a necessity in the field of engineering to share statistics, data, experimental findings, and technical information. Furthermore, it is important for engineers to be able to successfully communicate with other people in other fields of study, including the humanities. A globally conscious engineer that is unable to effectively articulate the humanitarian and environmental implications of projects will not be able to induce change. It is suggested that each experiment is followed by a written report and that reflective essays are assigned occasionally to ensure that students are making a connection between the technical experiments their humanitarian aspects.

### 6.4. Philanthropy

Philanthropy is the desire to take action or make donations in order to improve that lives of others. Engineering and philanthropy often go hand-in-hand, since engineers work to improve lives both domestically and internationally with buildings and inventions. Educating engineers on philanthropy will prepare them to tackle cultural, financial, and structural issues and barriers within the engineering

discipline, which will improve lives of people around the world.

Through this curriculum, industrial uses for algae are being researched, such as using algae to create cosmetics, discovering the nutritional value of algae for food production, how different lights affect oxygen production of algae, and more. These applications have the potential to benefit the quality of life for people worldwide, especially those living in impoverished areas. This integration of engineering and philanthropy teaches engineering students that engineering can, and should, be used for good.

## 7. Implementation

The experiments include critical thinking questions that allow students to understand the purpose of the experiments and to challenge them to think beyond the basics. These projects also encourage teamwork that will give students skills that they need to work in groups, both in the classroom and in the workplace. Students must work together in the lab to complete the experiments and collect the data, but also must communicate in order to write the lab reports. Lab reports provide students the opportunity to learn technical writing skills that are essential to success in engineering. Since all of the experiments include some type of analysis, students will learn to describe their results in a clear and professional manner.

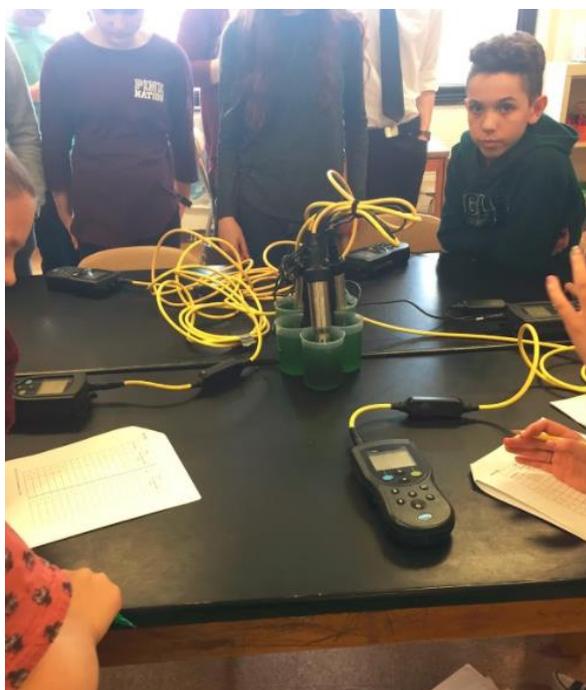


Figure 5. Hands-on learning in a seventh-grade advanced science class

The Algae Grows the Future Curriculum was implemented in three classrooms in Spring 2017 – two freshmen engineering classes and one seventh grade advanced science class. Instructors were able to align the curriculum with required teaching goals. For example, the flexibility of the curriculum allowed the instructor of the seventh-grade classroom to align the experiments with New Jersey Next Generation Science Standards. In all classes, students came up with innovative solutions to global issues through the semester project. The seventh-grade students were extremely engaged in the hands-on experiments and cultivated an excitement for algae, as shown in Figure 5.

The curriculum not only gave the students a basic knowledge of engineering and natural science, it also gave them an ethical foundation for the rest of their academic and career lives. In the future, the curriculum will continue to be implemented in college courses and outreach programs at elementary schools.

## 8. Website

In order to make the Algae Grows the Future curriculum, including experiments, handouts, instructional videos, and supplemental material, readily available to educators and to promote outreach, a website was developed. The website is intended to expand the implementation of algae-based learning from a local scale to national and global scale. Through the website, the Algae Grows the Future team will continue to update any research progress, add new experimental methods and applications, and encourage other educational programs to share how this curriculum has worked for them and make suggestions as to how to improve and add versatility to the program [6-7].

## 9. Conclusions

The "Algae Grows the Future" project is an innovative approach to using a live microorganism for integrating engineering and the humanities. The experiments of the project, such as calorimetry and the creation of an algae-based lip gloss, give students the fundamental skills and knowledge necessary to tackle some of the world's most challenging issues and encourage interest in solving them. The experiments demonstrate how algae-based creations can be used in today's society to be more environmentally friendly, healthy, and improve the quality of life in impoverished communities. They also give students a broad knowledge base of humanities and global issues that are commonly not included in the typical engineering program. The algae-based curriculum is currently being implemented in classrooms and feedback will allow for improvements.

## 10. Acknowledgment

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