Board 70: Impact of "Algae Grows the Future" Project on Promoting Engineering

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Impact of "Algae Grows the Future" Project on Promoting Engineering

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Abstract

The Algae Grows the Future project uses algae-based experiments for promoting science and engineering careers for K-12 and first year college students. Algae is a photosynthetic microorganism that is ubiquitous and has been used by many civilizations for various uses. These uses range for aquaculture feed to food for humans. In recent years the use has been expanded for biofuels, cosmetics, nutrient removal from wastewater and much more. The algae based experiments present engineering fundamentals and scientific principles, and provide students/educators hands-on experience with engineering experiments and problem-solving. The experiments also include concepts from both the humanities and social sciences, such as ethics, gender and racial biases. A subset of the modules described in this paper were tested with first-year students in engineering through the use of surveys and participation in a focus group. From the conducted surveys, it was determined that the first year engineering students had statistically significant increases in self-regulated learning strategies as well as increases in perceived confidence of learning after completion of the selected modules. These conclusions support the idea that algae-based learning promotes engineering education for students. Small focus groups of first year college students were also used to gauge student experiences from the project. The focus group found that the students were able to make better connections to their selected career path, and students were found to have a greater ability to persevere when presented with difficult engineering problems. While the study was only completed on a relatively small group size, the successful results from this group show that algae-based learning is a valuable project worth pursuing further. The overall goals for this project are to inspire students to pursue careers in engineering, as well as educate students on sustainability and the future use of renewable resources.

1.0 Introduction

1.1 Algae Grows the Future

Algae Grows the Future is a multidisciplinary project focused on creating an algae-based engineering education curriculum for K-12 and first year engineering students [1-4]. This 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 in Camden, New Jersey [5]. The CAS at Adventure Aquarium is focused on spreading the appreciation and education of marine life to the citizens of southern New Jersey, and work with the Algae Grows the Future team in order to increase public education on algae based engineering [3]. The curriculum and experiments present engineering fundamentals and scientific principles focusing on algae, and provide students with hands-on experiences using engineering activities, teamwork, and problem-solving. The value behind these experiments are that they include concepts from both the humanities and social sciences, such as ethics, gender and racial biases. The hands-on experiments conducted include growing algae and understanding the growth needs, calorimetry for the viability of algae-based foods, gas transfer, algae based gels, biofuels and electricity from algae. The goal of this type of integration between the humanities and the sciences, and the use of algae-based experiments, is to increase engineering interest and education within K-12 and first year engineering students. This project was implemented in our first-year engineering clinic course in four sections as a month long project. This project has also been carried out in middle schools near Rowan University.

1.2 Project Goals

Humanistic knowledge provides tools that allow the students of today to imagine a new future. With knowledge of culture, history, and the arts, humanistic studies can create a foundation for exploring and understanding the human experience [6]. The combination of technical and humanitarian studies allows engineers to make technological strides that benefit the world in more ways than ever before. The Algae Grows the Future project seeks to bridge the gap between engineering and humanities, allowing students to think outside of the technical realm. The goal of K-12 and college engineering first year outreach is to educate students on humanitarian topics to reach the height of their creative freedom within their educational careers. Algae-based experiments, lessons, projects, and supplemental materials expose students to real-world problems, fundamental math and science concepts, while allowing them to explore advocacy for topics that shape them into globally-conscious thinkers and creators.

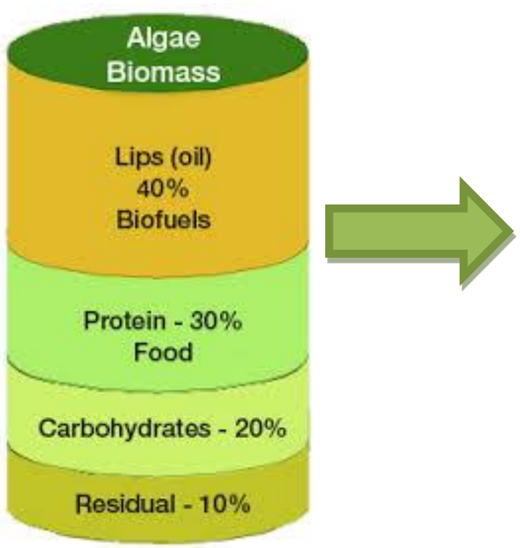
1.3 Globally-Conscious Learning

Algae are a common microorganism known to all [7-9]. Algae have been estimated to include anything from 30,000 to more than 1 million species [7]. This photosynthetic microorganism is present globally in abundance and uses CO_2 as a source of carbon. While everyone recognizes algae as a photosynthetic organism that is ubiquitous, it is rare that that we make a connection to the prospect of this microbe playing a significant role in impacting the future of this world and society.

Promoting global consciousness is an important part of the Algae Grows the Future project. Through the curriculum developed by the team, education and experiments combine learning about the scientific method and uses for algae by researching the needs for certain algae-based products around the world. Students not only learn about science and mathematics, but also about economics, efficiency, and different economical, social, and political barriers that may inhibit or prevent the use of certain products in different areas around the world [9]. This blend of engineering education and globally-conscious learning allows students to be able to consider the effects of different experiments and products in different cultures around the world, as well as consider the needs of the global population as a whole. It is important for the next generation to be knowledgeable of the different challenges faced around the world, and to be committed to solving them. This combination of engineering and humanitarian education will allow the future engineers to effectively approach and solve these issues.

2.0 Experiments

A number of simple hands on experiments were developed using algae to expose students to science and engineering fundamentals. These experiments can be used as individual activities or coupled together to make up a multi-week project. All experiments developed are detailed on our project website [10]. The multi faceted uses of algae is possible because of its composition as shown in Figure 1.



Applications of Algae

- Biofuels
- Gels for Medicine and Food
- Cosmetic Engineering
- Materials-Surfboards
- Medical - Healing wounds
- Electric battery
- Aquaculture Feed
- Animal Feed
- High Protein Content Food for human consumption
- Sequestering CO_2 gas
- Removal of Nitrogen Phosphorus
- Metal Removal
- Use as a Dye for Printing
- Use as a pet

Figure 1: Multifaceted use of Algae

2.1 Algae Growth Studies

Students are provided with small volumes of *Chlorella vulgaris*, a common algae species to conduct growth studies by varying conditions such as light intensity, CO_2 concentrations, mixing and nutrient (Nitrogen and Phosphorus) concentrations. Algae growth is monitored via optical density measurements using a spectrophotometer. Students plot the data to determine the growth rate. They also use MATLAB to model their data to determine the growth rate.

2.2 Algae Harvest Studies

Students use their cultivated algae to determine dry weights of algae produced. They are exposed to simple harvesting methods such as evaporation to expensive centrifuge methods. Chemical treatment to flocculate the algae using the conventional Jar Test experiment is also conducted. The typical coagulant utilized for this experiment is alum, as it is relatively cheap and works well to clump particles together. The addition of different concentrations of alum to jars containing the same concentration of algae, allows the determination of the optimal dose of alum needed to coagulate and flocculate the algae. Students graph and analyze their data using spreadsheets.

2.3 Algae Derived Biofuels

The dry algae harvested is further used by students to extract biofuel. Algal oil is converted into biodiesel through a trans-esterification process. Oil extracted from the algae is mixed with alcohol and an acid or a base to produce the fatty acid methylesters that makes up the biodiesel. This exposes students to chemical reactions and the need for more environmentally friendly chemicals for oil extraction.

2.4 Calorimetry

According to the World Hunger Program, about 795 million people in the world do not have the proper nutrition to live a healthy and active lifestyle. Furthermore, poor nutrition causes 45% of deaths in children under 5 around the world [11]. The promise behind using algae as a nutritional food source and its application in the battle against world hunger is explored using a calorimetry experiment. Through the process of calorimetry, the total number of calories in a food sample can be found by measuring energy exchange between a system and its surroundings. Students perform the calorimetry experiment using an empty, clean soda can as a calorimeter. The soda can is attached to a ring stand and filled with water of a known initial temperature. A food sample is lit on fire utilizing a match and then placed beneath the soda can. The final water temperature is measured using a thermometer after the food sample is completely incinerated. 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 overall change in temperature. The energy calculated is the energy of the food, also known as calories. Students begin by testing several food samples. At least one of these foods must be algae-based, and there are already algae-based chips and nutritional bars available. The students can then compare the energy content of the various food samples, along with their nutritional values, and analyze the nutritional benefits of algae. With the collected data relating to algae, including caloric amount and presence of protein and fats, students can evaluate whether or not algae can be proposed as a viable food source.

2.5 Cosmetics

The cosmetic industry includes skin care, haircare, lotions, and more. In this large industry consumers want products that are natural and beneficial to their health. Algae can be a beneficial ingredient in cosmetic products like beauty serums, anti-aging creams, and algal soaps. This is because Algae has a high fatty acid and vitamin content and has the ability to regulate sebum and collagen production. Since algae also has a good source of omega 3 fatty acids it can prevent dry skin and fight acne [12].

In this experiment, students learn how to create a common cosmetic product like lip gloss. Lip gloss contains oil, which acts as an emollient to moisturize and soften skin. 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 more safe and environmentally-friendly.

2.6 Algae Gels and Photosynthesis

Select algae species such as kelp contain sodium alginate. This is a polymer of glucose molecules. When combined with calcium acetate, a non-soluble calcium alginate is formed, creating a gel-like slime. Typically this product is used in the food industry in high end cuisine to trap flavors in the gel beads. Students make algae gel beads and then conduct a photosynthesis experiment with the gel beads.

The photosynthesis experiment provides the students with a hands-on experience to observe the effects of algae photosynthesis on oxygen levels. Students measure changes in oxygen levels for samples of algae both subjected to light and dark conditions.

Students may then apply this knowledge the bigger issue of climate change. Because photosynthesis is a recognized carbon sequestration mechanism, which mitigates the accumulation of greenhouse gases, this experiment makes it apparent that algae is a useful tool to achieve cleaner air and water.

2.7 Algae Batteries

Algae are microorganisms and as such carry a negative charge. During photosynthesis, algae produce electrons. Some of these electrons are exported outside the cell where they may be able to provide electric currents to power devices. Students assemble an algae battery to power an LED light using algae solution, and a metal cathode and anode.

2.8 Algae Game-Algae City

A game titled Algae City was developed for project dissemination for elementary and middle school children [13-14]. The game was developed through the Unity Game Engine. 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.

3.0 Engineering Education Applications

3.1 Semester Project

While students explore solutions to global problems through the algae experiments, they are asked to think about how these solutions can be applied to countries around the world. At the beginning of the curriculum, students are divided into small groups and assigned a country. Students are responsible for researching demographic, political, and economic information about the country, while identifying its specific engineering challenges. At the end of the semester, students give a presentation detailing how algae-based innovations could be implemented as a solution to solve healthcare, environmental, or materials problems in their country. The project encourages students to think about culture in other countries, while also promoting discussion about social barriers that would prevent innovative solutions from being successfully implemented in the country. This project builds upon teamwork, public speaking, and problem-solving skills amongst students.

3.2 Movies and Documentaries

In order to provide examples of real-world ethical challenges, catastrophes, and injustices, movies and documentaries are shown. These films/short videos are also valuable because they focus on issues discovered within the field of engineering. Some examples include *Apollo 13*, *Erin Brockovich*, *Rabbit Proof Fence*, *Henrietta Lacks*, *Hidden Figure*, *An Inconvenient Truth*, and *A Civil Action* [15-18]. The movies can be assigned among groups to watch on their own and present to the class. This activity can create a critical thinking exercise using the movies. It can encourage students to identify the issue presented, the consequences of the issue, and future changes to prevent a recurring issue.

3.3 Communication Skills

Without good oral and written communications, groundbreaking technical ideas can be misunderstood and ignored. It is crucial for engineers to be able to communicate their ideas to professionals outside of the technical realm such as humanitarians, politicians, and financial advisers. The humanitarian education of engineering students is useless without the ability to communicate their globally conscious ideas and environmental concerns. To combat this, oral and written communication skills are incorporated into the curriculum using technical reports, oral-presentations, and reflective essays. After each experiment, it is suggested that a written report is completed as well as periodic reflective essays that ensure students are making a connection between the technical experiments and their humanitarian aspects.

3.4 Curriculum Implementation

The Algae Grows the Future project has dedicated websites in order to make the developed curriculum, including the experiments, handouts, instructional videos, and some supplemental materials, readily available to educators on both the local and global scale [10]. Through this website, the team will continue to upload updated and newly created experiments, handouts, and instructional videos for use in classrooms.

The Algae Grows the Future project implements different algae-based experiments and lectures within the Rowan University Freshman Engineering Clinic program. Within this course, students are placed into teams and given different experiments to conduct as an introduction to engineering education. These courses used the algae-based experiments written by the Algae Grows the Future team to conduct within the classroom to implement this style of engineering education. These experiments often combined real-world issues with the experiment itself, so that students could make connections and devise solutions to problems with the algae experiments completed within the course.

4.0 Assessment

<u>First Year Engineering Clinic Course:</u> A subset of the learning activities described above including algae growth studies, algae harvesting, and algae applications such as cosmetics were implemented into a four-week long project run in the first year engineering clinic course. The impact of the learning activities were assessed via pre- and post-surveys (completed by 54 out of

69 students) and feedback from focus groups (a total of 9 participating students). Proper human subjects' approval was obtained prior to the conduct of this study. More details on this specific study are included in the authors' peer-reviewed journal article accepted for publication for the International Journal of Engineering Education [19].

4.1 Survey Results

Two validated survey instruments were used in the assessment of the project: (1) students' adaptive learning engagement in science [20]; and (2) the perceived competence scale [21]. The statements for the self-efficacy and self-regulation surveys are presented in Table 1.

Table 1: Statement for self-efficacy and self-regulation surveys

Statement for Average Student Responses for Self-Efficacy (Scale 1-5)	**Statement for Average Student Responses for Self-Regulation (Scale 1-5)**
I can master the skills that are taught.	Even when tasks are uninteresting, I keep working.
I can figure out how to do difficult work.	I work hard even if I do not like what I am doing.
Even if the engineering work is hard, I can learn it.	I continue working even if there are better things to do.
I can complete difficult work if I try.	I concentrate so that I will not miss important points.
I will receive good grades.	I finish my work and assignments on time.
I can learn the work we do.	I do not give up even when the work is difficult.
I can understand the content taught.	I concentrate in class.
I am good at this subject.	I keep working until I finish what I am supposed to do.

The analysis of the pre- and post-survey data was conducted across learning goal orientation, task value, self-efficacy, self-regulation, and learning within the context of the course in question. Reliability analysis across each of these constructs was performed to verify that the instruments could be applied to our context. Cronbach's alpha values ranging from 0.918 to 0.963 were obtained showing that the instruments demonstrated appropriate levels of internal consistency reliability [22]. Survey data were analyzed using both a paired t-test and the

Wilcoxon Rank Sign non-parametric equivalent test [23]. In general, the results from both statistical analyses were in close alignment with one another.

Important results from the surveys are listed below:

a) The students showed increases in task value through their participation in this project although effect sizes were small

b) The students' self-efficacy scores generally increased with a statistically significant increase in "I can figure out how to do difficult work" ($p=0.011$ for both tests; Cohen's $d = 0.364$).

c) Students self-regulation of learning showed statistically significant differences in multiple questions including "I continue working even if there are better things to do" ($p=0.025$ t-test and $p=0.029$ Wilcoxon Rank Sum test; Cohen's $d = 0.312$); "I concentrate so that I will not miss important points" ($p=0.008$ t-test and $p=0.009$ Wilcoxon Rank Sum test; Cohen's $d = 0.404$); "I do not give up even when the work is difficult" ($p=0.009$ both tests; Cohen's $d = 0.360$); and "I keep working until I finish what I am supposed to do" ($p=0.004$ both tests; Cohen's $d = 0.412$).

d) Perceived confidence for learning increased for all questions with a statistically significant increase in "I am capable of learning the material in this course ($p=0.007$ t-test and $p=0.004$ Wilcoxon Rank Sum test; Cohen's $d = 0.402$).

4.2 Student Focus Groups

Nine students participated in the focus group and were representative of all the disciplines present within the College of Engineering. These students met with an external researcher who was not involved in the instruction. The focus group questions were semi-structured and included the following six questions [19]:

1. How do you approach learning in First Year Engineering Clinic II?
2. Do you think the topics you learned as part of the algae project will be useful in your engineering professional development?
3. In the context of the algae project, do you feel that you were able to learn even if you encountered difficulties?
4. How interesting is the algae project to you?
5. What does engineering in a broader context mean to you?
6. In this course we have included examples that have social relevance such as how can engineering benefit different populations. Do you see this as being relevant to engineering?

The focus group data provided a more detailed understanding about the impact of the project on first year students. Students commented that they enjoyed working on a "real world" project. They also enjoyed the opportunity to conduct hand on laboratory experiments that required them to collect and analyze data. They indicated that the experiments allowed them to learn about laboratory experiment failure and perseverance. Students noted the value of active participation and expressed confidence in their ability to learn in the course. When asked to articulate the highlights of their experience they indicated the hands on experiments, the multifaceted use of algae, and the global impact of algae based economy.

90% of the surveys indicated that the participants had a better understanding of engineers and aspired to be engineers. All participants were able to name three global problems.

5.0 Conclusions

Using the Algae Grows the Future curriculum, first year engineering students have access to hands-on engineering activities that promote problem-solving, teamwork, and critical thinking. The development of this project shows the wide range of algae implementations in today's society, and how algae serves as a healthy, cost effective and environmentally friendly substitute in these different applications. There is even the potential for algae to improve nutrition and overall quality of life within impoverished communities. These activities also enable students to develop technical, communication, volunteerism and teamwork skills. The combination of engineering and humanitarian education will create a generation of engineers with a variety of skills needed to address local and global issues.

In the future, the Algae Grows the Future studies and surveys will be implemented into K-12 classrooms in order to determine the effects of this curriculum on younger students. Some algae experiments have already been conducted in middle schools to expose children to engineering education, and further experiments and studies can be conducted in order to draw further conclusions to the success of the curriculum. Within the University, this curriculum could be implemented within freshman engineering clinics on a larger scale in order to increase the number of students included within the survey. Some of these students surveryed will be exposed to algae-based learning, whereas other students surveyed will only be exposed to typical first year experiments. This way, the data collected can be compared to determine whether or not the Algae Grows the Future curriculum is helping students advance their engineering education. However, if trends continue, the effects of the algae-based curriculum should continue to be positive for students involved.

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