Leveraging Algae to Inspire Curiosity, Develop Connections, and Demonstrate Value Creation for First Year Engineering Students

Dr. Kevin D. Dahm, Rowan University

Kevin Dahm is a Professor of Chemical Engineering at Rowan University. He earned his BS from Worcester Polytechnic Institute (92) and his PhD from Massachusetts Institute of Technology (98). He has published two books, "Fundamentals of Chemical Engineering Thermodynamics" and "Interpreting Diffuse Reflectance and Transmittance." He has also published papers on effective use of simulation in engineering, teaching design and engineering economics, and assessment of student learning.

Dr. Cheryl A Bodnar, Rowan University

Cheryl A. Bodnar, Ph.D., CTDP is an Assistant Professor in the Department of Experiential Engineering Education at Rowan University. Dr. Bodnar's research interests relate to the incorporation of active learning techniques in undergraduate classes as well as integration of innovation and entrepreneurship into the engineering curriculum. In particular, she is interested in the impact that these tools can have on student perception of the classroom environment, motivation and learning outcomes. She obtained her certification as a Training and Development Professional (CTDP) from the Canadian Society for Training and Development (CSTD) in 2010, providing her with a solid background in instructional design, facilitation and evaluation. She was selected to participate in the National Academy of Engineering (NAE) Frontiers of Engineering Education Symposium in 2013 and awarded the American Society for Engineering Education Educational Research Methods Faculty Apprentice Award in 2014.

Dr. Scott Streiner, Rowan University

Dr. Scott Streiner is an assistant professor in the Experiential Engineering Education Department (ExEEd) at Rowan University. He received his Ph.D in Industrial Engineering from the University of Pittsburgh, with a focus in engineering education. His research interests include engineering global competency, curricula and assessment; pedagogical innovations through game-based and playful learning; spatial skills development and engineering ethics education. His funded research explores the nature of global competency development by assessing how international experiences improve the global perspectives of engineering students. Dr. Streiner has published papers and given presentations in global engineering education at several national conferences. Scott is an active member in the Center for the Integration of Research, Teaching, and Learning (CIRTL) both locally and nationally, as well as the American Society for Engineering Education (ASEE) and the Institute of Industrial and Systems Engineers (IISE).

Dr. Kauser Jahan, Rowan University

Kauser Jahan, is a Professor of Civil and Environmental Engineering at Rowan University. She received her B.S.C.E. from the Bangladesh University of Engineering and Technology, an MSCE from the University of Arkansas, Fayetteville and a Ph.D. from the University of Minnesota, Minneapolis. Her passion as an educator and mentor has been recognized by many professional organizations over the years. She is the recipient of the Gloucester County Women of Achievement Award, Lindback Foundation Teaching Award, the NJ ASCE Educator of the Year award, the Gary J. Hunter Excellence in Mentoring Award, the ASEE Environmental Engineering Division Meritorious Service Award, the ASEE Women in Engineering Division Sharon A. Keillor Award and the WEPAN Women in Engineering Initiative Award. She has been instrumental in establishing the Attracting Women into Engineering, the Engineers on Wheels and Engineering Clinics for Teachers programs at Rowan University. She has served as the Institutional Representative and Advisory Board Chair for the Women's Professional Network at Rowan University for six years and currently is an advisory board member of the New Jersey Chapter of the American Council on Education (ACE) Office of Women in Higher Education (OWHE). She received a Fulbright award in 2015.

Dr. Richard T. Cimino, Rowan University

Dr. Richard T. Cimino is a Senior Lecturer in the Otto H. York Department of Chemical and Materials Engineering at New Jersey Institute of Technology. He received his Ph.D in Chemical & Biochemical Engineering from the Rutgers University, with a focus in adsorption science and the characterization of porous materials. His research interests include engineering ethics and process safety, and broadening inclusivity in engineering, especially among the LGBTQ+ community. His previous funded research has explored the effects of implicit bias on ethical decision making in the engineering classroom.

Full Paper: Leveraging Algae to Inspire Curiosity, Develop Connections, and Demonstrate Value Creation for First Year Engineering Students

Introduction

The Rowan University engineering curriculum includes an interdisciplinary first year sequence, Freshmen Engineering Clinic I and II (FEC I and II), which is required for students in all engineering disciplines. Each course has one 75-minute "unlecture" period and one 165-minute "laboratory" period each week. Instructional objectives for the sequence include general engineering skills such as engineering communication, collection and presentation of data, basic statistics, dimensional analysis and unit conversions, etc. During the 2018-2019 academic year, FEC I and II were each offered in 17 sections of approximately 20 students each. Each section of FEC II, which is in progress at time of writing, is incorporating two major projects, each of which is 5 weeks in duration.

Rowan University is also a partner institution of KEEN, the Kern Entrepreneurial Engineering Network. The goal of KEEN is to promote "entrepreneurial mindset" in students. The entrepreneurial mindset as defined by KEEN is embodied by the "three C's": curiosity, connections, and creating value [1]. One of the predominant features of KEEN network activity is the collection and dissemination of exemplar curriculum that promotes the three C's. A searchable collection is available at [2].

Faculty at Rowan University have devised a five-week project for FEC II that explores algae farming, focusing on the production of algae-derived biofuels but also examining other possible applications for algae. The project is intended to further the general instructional objectives of FEC II while also giving students an experience that enhances development of the three C's. At the time of writing, six of the 17 sections of FEC II are integrating the algae project as one of their two major course projects. This paper describes the project and explains the strategy for assessing student achievement relative to the three C's.

Project Overview

The algae project is conducted in teams (typically four students) and includes four graded deliverables:

- Write-ups on two laboratory experiments: an algae growth rate experiment and a gas transfer experiment
- A presentation on ethical and/or environmental considerations stemming from algae farming
- A final report proposing a preliminary design concept for an algae farm located in a specific country.

Each student team centers their project on biofuel production and algae farming in a specific country. To ensure variety across the class, the faculty identified five regions: South America, Europe, Africa, Asia, and Oceania. Each team was assigned a region and instructed to choose a country located in that region. Note that North America is excluded because one of the purposes of the project was for students to learn about a country that was different from their own and account for regional and cultural factors that could impact their proposed plan to grow algae or to market specific products.

This section contains a summary of each of the major activities associated with the project.

Algae Growth Rate Lab

The purpose of the experiment was to identify factors that stimulated the rate of algae growth. In the default procedure, 125-mL flasks were filled with 100 mL of water seeded with algae and nutrients (solutions containing nitrogen and phosphate), aerators were submerged in the water, and the flasks were placed in shaker trays located under fluorescent lamps. The experiment lasted 10 days. Each day, a spectrophotometer was used to measure the absorbance at 625 nm for the liquid in each flask, and a calibration equation (provided by the faculty) was used to calculate an estimate of the dry mass of algae contained in the flask. "Control" flasks were prepared and maintained by the course lab technician using this default procedure. Each student team received two flasks and carried out their own 10-day algae growth experiment, following the default procedure except for one variation chosen by the team. Examples of these variations included: increasing or decreasing one of the nutrient concentrations, placing the flask on a stable countertop instead of the shaker table, not adding an aerator to the flask, etc.

In addition to collecting data for 10 days, each student team used MATLAB to fit a kinetic growth model to their data, specifically the "logistic model" [3]. Students also pooled the final algae dry mass data within each course section. Thus, in a section with 5 teams, each team was responsible for collecting data from their own two flasks, but analyzed the "day 10" data from all 5 pairs of flasks representing five different factors studied. One of the course topics was statistics including mean, standard deviation, and 95% confidence intervals. Thus, in their lab write-ups, students were expected to present quantitative conclusions regarding whether any of the factors studied led to algae concentrations that were statistically different from the control flasks at the end of 10 days of growth. The students also had to reflect on whether their country had the necessary support structures to be able to grow algae efficiently. By consistently integrating the country context throughout the five-week project, students were scaffolded towards the major deliverable for the project but also had multiple opportunities to reflect on the differences in resources depending on the country context.

Gas Transfer Lab

This experiment studied the rate of dissolution of gas in water. Students added cobalt chloride and sodium sulfite solutions to a beaker containing approximately one liter of water that was being continuously stirred, and monitored the oxygen content with a Dissolved Oxygen Probe. The addition of these binding chemicals caused the oxygen level, which was initially near its saturation level of ~9.1 mg/L, to drop to 2-3 mg/L. Students then turned off the stirrer and turned on an aerator that was submerged in the water, and monitored the dissolved oxygen content as it increased. The students observed that even with continuous aeration, it took ~10 minutes for the dissolved oxygen content to level off at approximately its saturation level. Students also calculated an overall gas transfer coefficient for the system [4]. The lab submission included answers to a series of reflective questions on the implications of the experiment regarding maintaining a life-sustaining environment for aquatic organisms like algae. It also asked the students to consider whether aeration was beneficial for algae growth overall and if so, how they would seek to implement aeration within their country context.

Alginate Gels

The project also included a third lab experiment involving making sodium alginate gels. Because this lab fell very close to the end of the five-week time frame, there was no graded write-up of the experiment, but students used information learned through the lab in their final country reports. Alginate is a polymeric compound that can be extracted from all brown algae [5] and is used in the food industry as a thickening and stabilizing agent. As an illustration of its properties, the students made alginate gels in different shapes- beads and worms.

Students started with a beaker of calcium chloride solution and a beaker of sodium alginate solution. The alginate solution is a viscous liquid, but when small amounts of it are added to the calcium chloride solution, it congeals into a gel, and this happens quickly enough that the gel maintains the approximate shape of the introduced liquid. Consequently, adding the alginate dropwise produces small beads of gel, and adding the alginate in a thin continuous stream produces "gummy worms." After completing the lab, students brainstormed possible applications for materials with the observed properties. More generally, the lab was used to launch a broader class discussion of algae applications beyond biofuels. Each team then researched possible algae applications and how these might apply as opportunities in their specific country.

Ethics Presentation

Each team delivered a 6-8 minute presentation on ethical and environmental considerations related to algae and biofuels. Teams were instructed to identify one or two "major ethical issues" surrounding biofuels, as well as one or two "major environmental risks" associated with algae. Students were encouraged to link these issues and risks to their particular country context if possible. During their presentations, students explained the issues they had identified, discussed how it applied to their specific country, and then outlined mitigation strategies that could be used to address the problem and minimize the risks. Students were provided with a list of 10 links they could use to get started in researching ethical and environmental considerations (see for example [6] and [7]), but were instructed that these were only a small sampling of the available literature. Students were expected to do research beyond the instructor-supplied resources and to document sources for the factual statements and claims made throughout the presentation. This research was also useful in the final country report.

Final Country Report

The algae project culminated in a final report, with a specified maximum of 8 pages not including appendices. Students discussed the opportunities and challenges related to algae farming and the production of biofuels in their country, drawing information from all of the lab experiments as well as from the literature. The prescribed outline for the final report was as follows:

- Country Introduction and Problem Definition
- Algae Growth Conditions and Availability
- Algae Farm Design and Scale Up
- Broader Impacts of Growing Algae
- Discussion of Algae Applications and Next Steps
- References and Appendices

Students had to be mindful of regional and societal differences in discussing algae farm design, with considerations including differences in ambient temperatures, availability and access to electricity and water, demand and markets for biofuels and other algae-derived products, and local laws and customs in the specific country.

Assessment of the "Three C's"

Among the topics for Freshman Engineering Clinic II are: engineering communication, engineering ethics, statistics, programming with MATLAB, engineering economics, product development, and intellectual property. Thus, a good project for integration into FEC II should use and reinforce most or all of these topics, and the algae project does so. An additional goal of the algae project is to contribute to instilling the entrepreneurial mindset in students through the KEEN "three C's". The rubric presented in Appendix A was used to assess how well each final report embodied the "three C's." This rubric measures (on a scale of 1-5) the quality of nine aspects of the report. Four of these relate to the quality of the writing: Organization, Clarity and Presentation, Abstract or Executive Summary, and use of Figures and Tables. The other five relate to the content: Scenario, Algae Growth Studies, Farm Design and Scale Up, Broader Impacts and Next Steps. These five are mapped to the three C's as follows:

Curiosity- Students exhibited curiosity through engagement in the project and their independent research on algae applications in general as well as on their specific country. Thus, the "scenario" aspect of the rubric is used to assess curiosity. The descriptor for excellence in this aspect of the project is: "The report gives a thorough and concise description of the problem to be solved. It demonstrates an understanding of algae, algae biofuels, and algae farm production in general, and specifies relevant unique features of the team's country."

Connections- The project incorporates several opportunities for making connections. One crucial example was that within the algae growth lab experiment, students needed to apply statistics to analyze the significance of the findings. In the final report, students compared and contrasted their findings regarding ideal algae growth conditions to the conditions and resources in their specific country, and included the raw data from the algae growth studies as an Appendix. More broadly, students were expected to draw from all of the lab experiments and from their research on ethical and environmental challenges to inform their analysis of the viability of algae farming in their specific country. Thus, the "algae growth studies" and "farm design and scale up" portions of the rubric are used to assess connections. We note that the importance of "trade-offs" is emphasized in the "farm design and scale up" rubric. While the students were not capable of completing a rigorous detailed design of an algae farm as first year students who have studied the topic for 5 weeks, they were able to and expected to identify significant design considerations, such as features that would enhance the productivity of the farm but also add significant cost.

Creating Value- The project is an exploration of how algae farming can create value in a specific country. All teams investigated the prospect of producing algae-derived biofuel in their country, and also had the opportunity to discuss other possible applications for algae in their country. The "Broader Impacts" and "Next Steps" sections are used to assess creating value. The "Broader Impacts" section challenges students to discuss the positive and negative aspects of algae farming and to analyze how algae farming can create value, not only in terms of making saleable products but also in terms of global, societal, and environmental impacts. The "Next Steps" section requires students to recognize what questions still need to be answered in order for algae farming to be successfully and effectively implemented in the chosen country.

Summary

This paper describes a 5-week project for an interdisciplinary first-year engineering course. The project includes laboratory experiments, mathematical modeling, and research in the open literature. The project is presented in a way that is intended to promote the entrepreneurial mindset in students while also furthering the general instructional objectives of the course. The authors have crafted a rubric that can be used to assess how well each student team exhibits each of the KEEN "three C's" in their final reports. This data is not yet available at time of writing, but will be presented at the conference.

Literature Cited

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Appendix A: Rubric Used for Evaluation of Algae Final Country Reports

Organization	5	Report is extremely well organized. Every section has a descriptive heading and a clear and explicitly stated purpose. Cross-referencing to figures and appendices is used effectively wherever it is needed.
	3	Report is divided into reasonable sections but some material may be repeated or oddly placed. Cross-referencing to figures/appendices is generally used but sometimes missing or haphazard.
	1	The report shows little or no organization. Reader has to expend unreasonable effort to figure out what's going on.
Clarity and Presentation	5	Report is written with great clarity and is easy to read and understand. Report is concise and free of grammatical and spelling errors.
	3	Report conveys information adequately, but is at times unclear, wordy and/or unfocused. The number of instances of grammar and/or spelling errors is noticeable but not outrageous.
	1	The report fails to convey information clearly. It has so many problems with ambiguous phrasings, lack of focus, grammar, and/or spelling, that the reader can't follow it.
Abstract/Exec Summary	5	Summary stands on its own and provides a compelling overview that includes statement of objectives, provides quantitative results, and summarizes conclusions. and recommendations
	3	Summary is generally adequate but misses some pertinent information.
	1	Summary doesn't address fundamental questions about project, such as objectives, approaches, conclusions and recommendations.
Figures, Tables, Graphics	5	Illustrations, figures and tables are clear and informative, well positioned within report, and captioned in sufficient detail to stand on their own.
	3	All needed illustrations, figures and tables are present and contain useful information, but sometimes lack clarity and/or aren't well described in the captions.
	1	Illustrations, figures and tables are missing or incomprehensible. Captions are missing or haphazard.
Scenario	5	The report gives a thorough and concise description of the problem to be solved. It demonstrates an understanding of algae, algae biofuels, and algae farm production in general, and specifies relevant unique features of the team's country.
	3	The report demonstrates a reasonable understanding of algae and algae biofuels as well as the unique features of the team's country, but the discussion isn't as clear, thorough, and/or concise as it could be
	1	The report fundamentally misunderstands or misrepresents the premise of the project.

Algae Growth Studies	5	The main text gives an accurate, thorough, clear, and concise explanation of the procedures for the algae growth studies and the results obtained. The report demonstrates a full understanding of the significance of the data that is informed by the results of statistical analyses. Complete raw data and statistical analyses are included in the Appendix.
	3	The report includes procedures and results for the algae growth studies. The relevant information is accessible but could be presented more clearly or concisely. The analysis of results is broadly accurate but has minor errors and/or doesn't fully demonstrate understanding of the significance of the results.
	1	Vital information regarding the procedures for algae growth studies is wrong or missing. The results are missing or contain fundamental errors.
Farm Design and Scale up	5	The farm design and plan for scale up is extremely well thought out and is presented clearly. The design is informed by accurate quantitative calculations and a realistic interpretation of both the algae growth studies and results obtained from mathematical models. The relevant decisions and assumptions used in the calculations and construction of models are explained and justified. There is an insightful discussion of relevant trade-offs in design parameters.
	3	The farm design and plan for scale up are broadly reasonable. They are informed by algae growth studies and results of mathematical modeling, but the calculations and models contain minor errors or some dubious/unjustified assumptions. Discussion of trade-offs in design parameters is accurate but somewhat cursory.
	1	There are fundamental errors in the calculations and/or the modeling approach. The design is fundamentally unsound, and/or doesn't address the stated problem.
Broader Impacts	5	The report presents an excellent analysis of global, societal, economic, ethnical and environmental issues surrounding algae and algae farms. This includes a thorough and accurate understanding of relevant unique factors associated with the specific country and region.
	3	The report presents an acceptable analysis of global, societal, economic and environmental issues. The discussion is accurate but doesn't progress much beyond broad and obvious statements. Discussion of unique relevant factors associated with the specific country and region are also accurate, but cursory.
	1	The discussion of global, societal, economic and environmental issues is fundamentally flawed. Components are missing completely, contain errors of fact, or show fundamental misunderstandings.
Next Steps	5	The report presents an insightful discussion of next steps, commenting on both the necessary next steps to advance the proposed design and on additional possible applications for algae and algae farming.
	3	The report presents recommendations for next steps that are reasonable, but are broad and could be more insightful.
	1	The report fails to make recommendations, or makes recommendations that are fundamentally flawed and unsound.