AC 2011-1105: BRIDGING THE GAP BETWEEN SCIENCE AND ENGINEERING FOR HIGH SCHOOL STUDENTS THROUGH AN INNOVATIVE BIOFUEL RESEARCH PROJECT

Jeffrey R Seay, University of Kentucky

Assistant Professor of Chemical and Materials Engineering

Wesley Allen Whipple, University of Kentucky

Bridging the Gap Between Science and Engineering for High School Students through an Innovative Biofuel Research Project

Abstract

This contribution will outline the details of a project to introduce high school students to the principles of sustainability and renewable energy by linking them with undergraduates working on a multidisciplinary project to manufacture biodiesel from vegetable oil and convert the glycerol side product to marketable specialty chemical products. The high school seniors participating in the project have worked with undergraduate researchers in chemical and mechanical engineering to operate a small scale biodiesel plant and glycerol conversion reactor at the Paducah Extended Campus of the University of Kentucky College of Engineering. In addition, the students operate a quality control laboratory and conduct research experiments designed to improve the biodiesel manufacturing process and optimize the process for utilizing the glycerol side product. Feedstocks utilized for the biodiesel process include unused soy bean oil and waste vegetable oil from the high school cafeteria and local restaurants. The fuel produced will be used to power a heater in a student run greenhouse on the high school campus. As part of the research experience, the students explore both the economic and environmental impacts of this renewable fuel process.

Bridging the Gap Between Science and Engineering

One of the principle objectives of this project has been to bridge the gap between science and engineering for perspective students of chemical engineering. Students considering a major in chemical engineering have typically been exposed to chemistry in high school and for many of them that has included some laboratory experience. However, students who choose chemical engineering as a major are often unaware of exactly what a chemical engineer does, or how chemical engineering differs from chemistry. Because the high school curriculum typically doesn't offer engineering classes, students considering a major in engineering don't have a frame of reference as to what to expect from college level engineering classes.

One difference between laboratory science and engineering has to do with scale. Tasks that are accomplished by hand in the laboratory are impossible to accomplish without the use of specialized equipment on a larger scale. The production of biodiesel from vegetable oil is a prime example of a process that can be used to demonstrate the application of chemistry on an industrial scale. Furthermore, this process illustrates how engineers address the specific challenges of scaling up a chemical production process beyond the laboratory scale. By introducing students to the chemistry of biodiesel on the laboratory scale that they are familiar with, and then allowing them to operate the larger equipment, the students are able to see this concept in action.

Furthermore, students are increasingly interested in the concepts of sustainability, renewable energy and biofuels. A recently constructed demonstration scale biodiesel plant on campus has been used as an outreach project to introduce high school chemistry students to chemical engineering. Therefore, hands on examples that utilize the themes of sustainability can be useful to not only introduce students to engineering, but also to bridge the gap between science and engineering. By utilizing both the chemistry lab and the research scale biodiesel plant, participating high school students are able to directly experience for themselves how the challenges of the chemistry lab differ from the challenges of manufacturing chemicals on an industrial scale.

Outreach Project Outcomes

Beyond the technical goals of the research, this project has three specific outreach outcomes:

- Introduce the high school and undergraduate students to the concept of sustainability and sustainable process design,
- Introduce high school students to the field of engineering through participation in an active undergraduate design project,
- Raise the students' awareness of design engineering through introduction to the tools and methods used by engineers in solving design problems.

The high school students' knowledge and opinions towards sustainability and environmental issues and their knowledge of the chemical engineering profession were assessed before participation by use of a survey. The purpose of the survey was to gauge the student's attitudes and opinions on sustainability and engineering. The results of this survey as well as the anecdotal reports from the participating students will be presented in this contribution. Finally, some of the specific challenges involved in including high school students in active research projects will be addressed.

People, Prosperity and the Planet Program

The high school outreach program is a direct outcome of participation in the U.S. Environmental Protection Agency's People Prosperity and the Planet (P3) Design Competition by a team of undergraduates at the University of Kentucky Paducah Extended Campus. The project undertaken by the P3 design team is to design a process for converting the glycerol side product of the transesterification of vegetable oil to biodiesel into value added specialty chemical products through the application of process design and process intensification methodologies. This project is a multidisciplinary collaboration between chemical engineering and mechanical engineering students.

Products such as acrolein, acrylic acid, hydroxyacetone and propylene glycol can all be easily produced via the catalytic dehydration of glycerol[1,2,3,4]. A reaction tree based on glycerol dehydration chemistry is illustrated in Figure 1, below. The P3 design team project also requires laboratory experimentation to determine the optimized reaction parameters for the glycerol dehydration reaction.

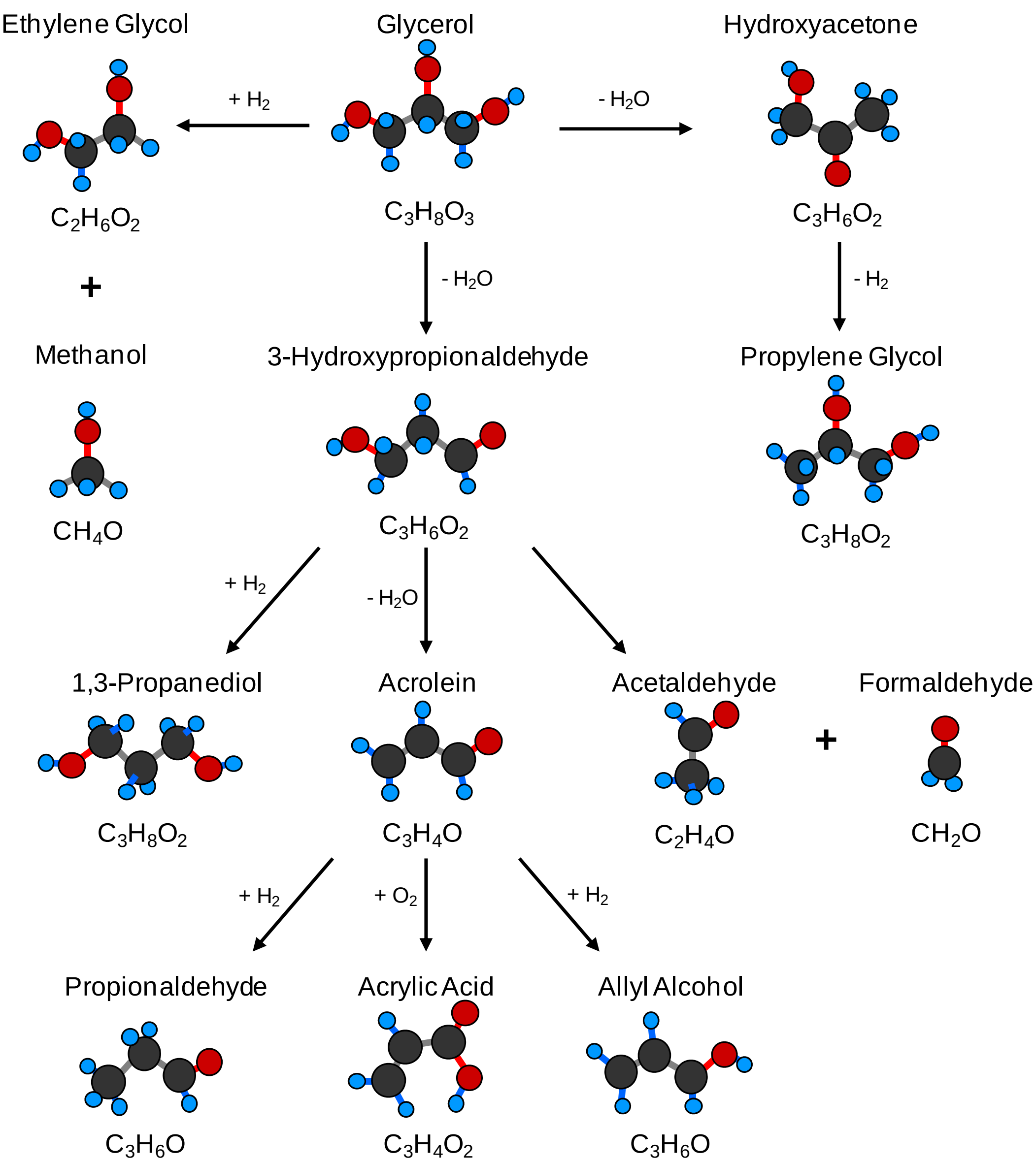

Figure 1. Glycerol dehydration product tree [5]

A select group of 5 high school seniors was chosen to participate in the year long P3 design project. The students selected had all completed the AP high school chemistry course and had passed the AP exam. The students' choice of college was not a factor in allowing them to participate in the program. The students come in small groups during the school day to participate with the undergraduate students on laboratory experiments and process design activities. The high school participants conduct quality control and reaction engineering experiments in the laboratory as well as operate the larger scale biodiesel production equipment.

Typically, the students come to campus 2 or 3 at a time during breaks in their academic class schedule. The students schedule their campus visits independently. The university research team utilizes an online calendar to schedule laboratory time, so the high school participants are able to see when research work is being done, and there schedule their visits accordingly.

By working side by side with the undergraduates, the students are able to work and contribute at a level beyond what they would typically be able to do. Although the undergraduates were given no special instructions with regard to working with the high school students, they were encouraged to include them in planning and project discussions. By involving the high school students in this process, they have been able to experience the process of analyzing the entire life cycle of a production process. Since the glycerol used as a feed stock for the production of the various C3 species is generated as a side product of biodiesel manufacture, the students are able to see how a potential waste product can be used as a feed for another process. This is a skill that is important to engineers, but one that the students are unlikely to see in a high school chemistry class.

On Campus Biodiesel Production

As previously described, a research scale biodiesel plant has been constructed at the University of Kentucky Paducah Extended Campus. The process is based on the open source Appleseed Biodiesel Processor design. A photo of the equipment setup is shown in Figure 1, below.

Figure 2: Research scale biodiesel processing equipment

The Appleseed Processor is built using a converted electric hot water heater. Since a heated, insulated, temperature controlled reaction vessel is needed for the transesterification reactor, a modified hot water makes an ideal reactor. In addition to the Appleseed Processor for carrying out the transesterification reaction, the process also includes storage tanks, a glycerol/water separator vessel and a crude biodiesel wash vessel.

Each of the unit operations in this process can be directly mapped to a specific piece of laboratory scale equipment. For example, the Appleseed Processor can be mapped to the beaker, hot plate and stirrer used to perform the transesterification reaction in the laboratory and the crude biodiesel wash tank and glycerol / biodiesel separator vessel can be mapped to a laboratory separatory funnel.

Glycerol Dehydration Research

Since the scope of the P3 design project focuses on glycerol dehydration chemistry, the participating high school students have also gotten the chance to use the glycerol dehydration mini-plant, constructed for studying the kinetics of the vapor-phase heterogeneously catalyzed reactions. A photo of the mini-plant is illustrated in Figure 2, below.

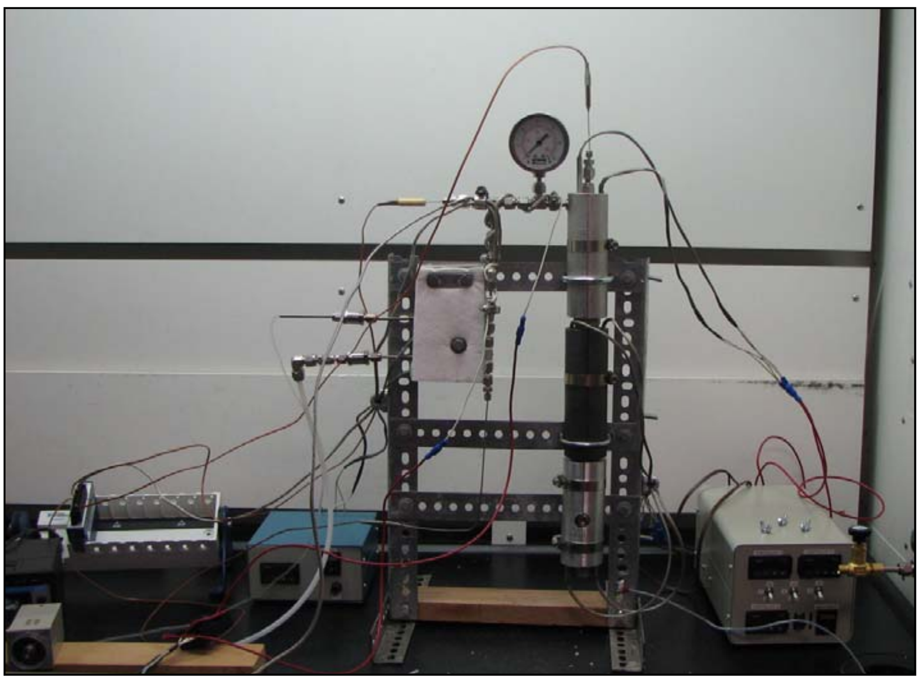

Figure 3. Laboratory mini-plant for glycerol dehydration chemistry.

The mini-plant models, on a bench scale, the front end of a process based on glycerol dehydration chemistry. The mini-plant setup includes the feed system, a vaporizer for operation in the vapor phase, and the fixed bed catalytic reactor for carrying out the glycerol dehydration reaction. The purpose of this mini-plant is to allow researchers the opportunity to test different operating conditions to optimize the process. Again, getting the chance to work with this mini-plant serves as another opportunity to illustrate some of the principles of engineering that extend beyond the high school chemistry class. Since the mini-plant models multiple unit operations, the high school students were able to experience some of the systems thinking used by engineers to design and optimize complex processes.

Although the high school students were able to easily follow the stoichiometry of the reaction, the application of systems engineering and statistical design of experiments techniques to optimize the reaction parameters was new to them. Again, by letting the high school students see the tools and methods of process engineering being applied in the context of chemistry – a subject they were comfortable with – they were able to get an understanding of how engineers work and what engineers do. This was a valuable experience that they would not be able to get in a typical high school environment.

Assessment

An assessment survey was completed by the high school students selected for the design team prior to participating in the P3 design project. The purpose of this study was to gauge responses in 4 categories:

- Interest in sustainability and renewable energy
- Perceived knowledge of biodiesel and biofuels in general
- Perceived knowledge of engineering job functions
- Future college plans

The students were asked a series of questions in each category. The results of the assessment survey are reported in Figures 4 – 7, below.

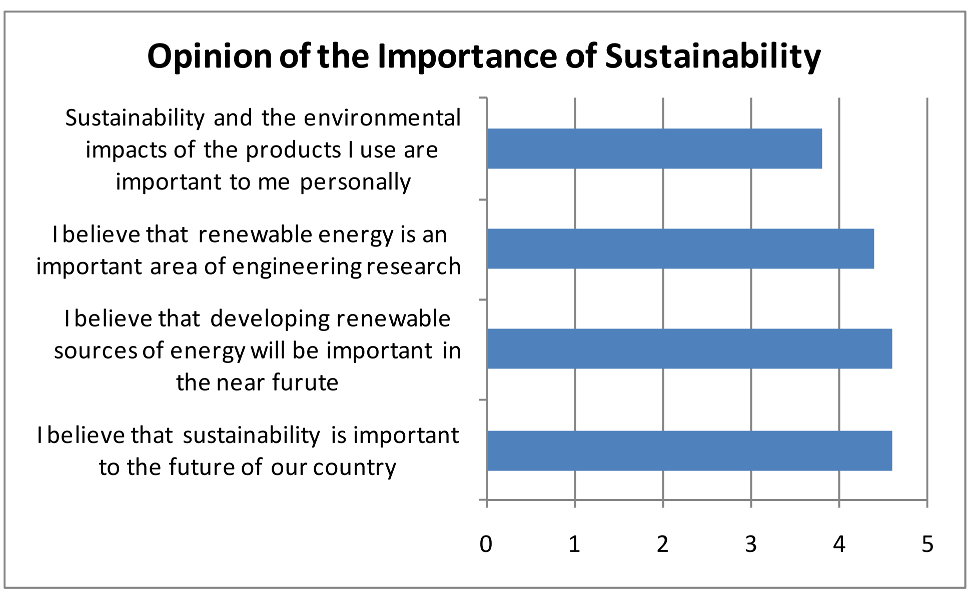

Figure 4. Results of assessment of students' opinion of the importance of sustainability

The results of this set of questions illustrated in Figure 4 indicated that the students came into the project with a strong opinion on the importance of sustainability and research in the area of renewable energy. However, the lower score of the students' belief in the importance of the sustainability and environmental impacts of the product they use does imply a disconnect between sustainability as an abstract concept and sustainability in the students' personal lives. However, this interest in sustainability indicates that it is important to stress how engineers contribute to topics like renewable energy, life cycle assessment and pollution prevention.

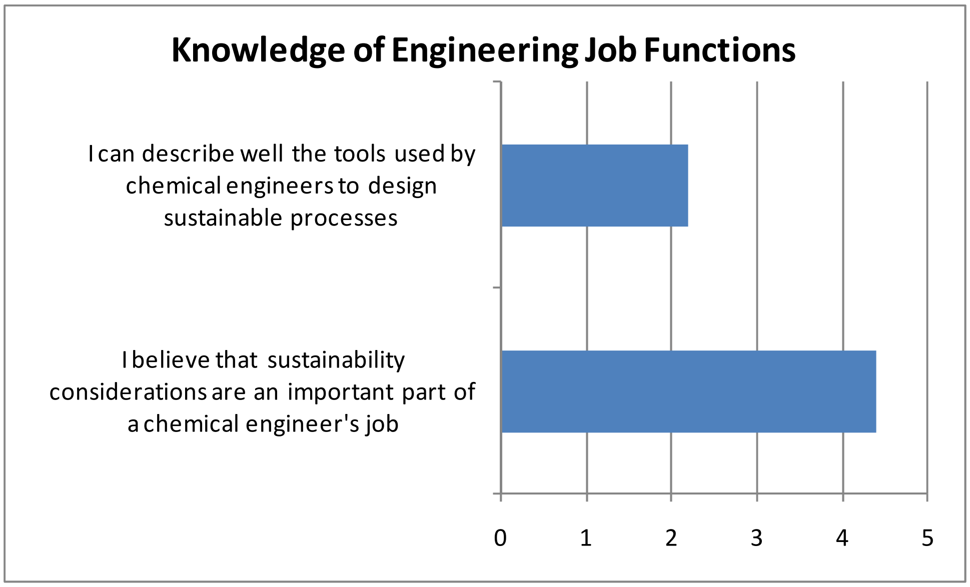

Figure 5. Results of students' self reported knowledge of engineering job functions

The results of this set of questions shown in Figure 5 indicated that the students' believed that sustainability was an important part of the job of a chemical engineer, but were generally unfamiliar with the tools used by chemical engineers to incorporate sustainability into their process designs. This is an expected result since students are typically not exposed to engineering concepts at the high school level. This is quite different from the subjects of mathematics and chemistry, which high school students have typically experienced. However, participation in the P3 design project with the undergraduates will expose the students to the tools and methods commonly used by process engineers.

The results of this set of questions shown in Figure 6 assessed both the students' self reported familiarity with the concept of green chemistry and their self reported knowledge of the specifics of biofuels and biodiesel production in particular. Clearly, although the students reported that they were generally familiar with the term green chemistry, they were less confident in their knowledge of biofuels and biodiesel manufacture. Again, the students' awareness of green chemistry underscores the need to incorporate sustainability into the undergraduate curriculum to engage students in the future. Finally, since these are clearly topics that students have knowledge of and an interest in, demonstrating them can also serve to bridge the gap between science and engineering.

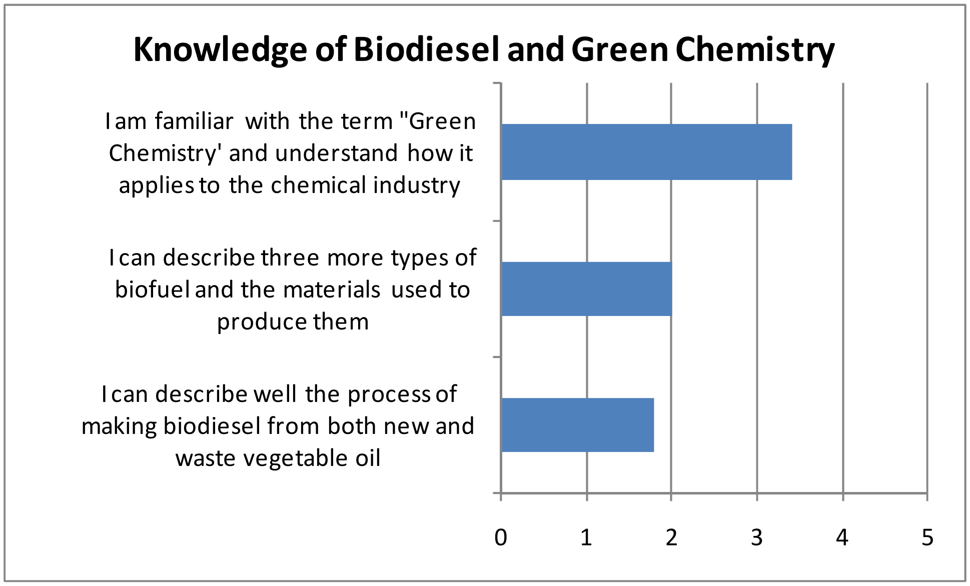

Figure 6. Results of students' self reported knowledge of biodiesel and green chemistry

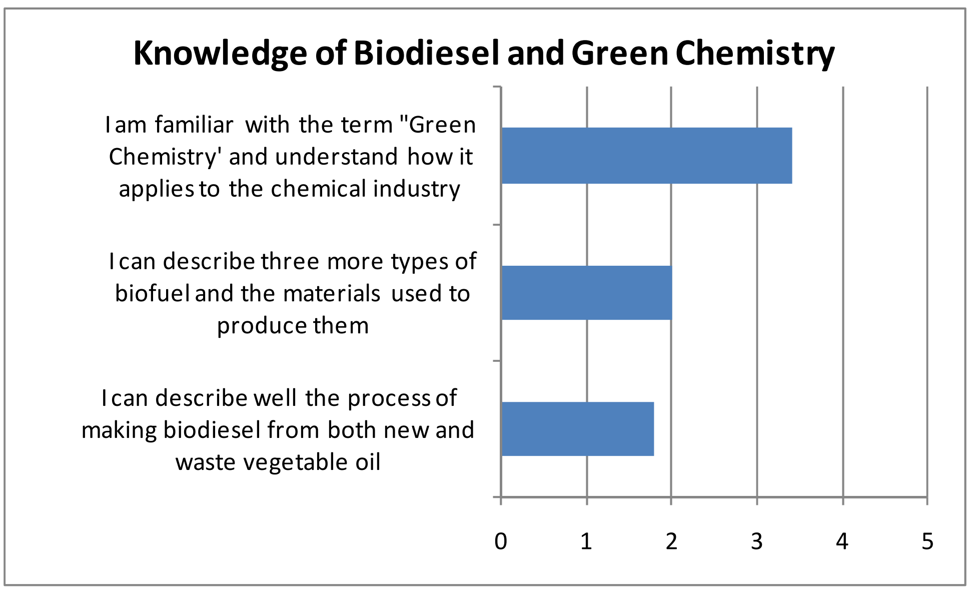

Figure 7. Results of students' self reported future college plans.

The results of the set of questions illustrated in Figure 7 indicate that the students participating as part of the P3 design team have a strong interest in chemistry and chemical engineering. Furthermore, the students showed a strong belief that chemical engineering is an appropriate major for those interested in careers involving sustainability.

Project Challenges

Involving high school students into undergraduate research labs presents a special set of challenges. Safety is the first priority with anyone working in a laboratory, so a special laboratory safety training session was conducted with the high school students and their parents so everyone would be aware of any specific hazards and all laboratory rules and procedures. In addition, it has been important to coordinate with high school administrators and faculty to ensure that they are aware of all work being conducted off campus. Regular conversations and status updates are provided to the high school principle to ensure that the students are spending their time at the university in a productive manner.

One of the particular challenges in organizing this project as a faculty member is planning for how the high school students should spend their time on campus. Even more so than with undergraduates, the interactions with the high school students have to be carefully planned. For each visit, a specific laboratory task must be planned that can be completed, or at least run to a convenient stopping point in the time allotted. This was especially difficult with an active research project. Since the outcomes from one set of experiments often guide the next set of experiments, planning more than one or two visits ahead was rarely possible. As a result, the time commitment was much greater that initially anticipated. Even though participation in the research project was limited to students who had taken and passed the AP Chemistry exam, a total of 5 students requested to participate. In order to avoid turning down an interested student, all five were allowed to participate. In hindsight, due to the highly hands-on nature of the research experiments, 3 students would have been a more reasonable number. Despite the additional faculty time commitment, all of the interested high school students were accommodated and all were able to participate in the project.

Finally, scheduling laboratory time was a challenge. Working around the class schedules of the students and the teaching schedule of the faculty was problematic. This was alleviated somewhat by the use on an online calendar; however, the high school students were allowed to self schedule their on-campus time. In the future, a better plan would be to set aside a specific day and time in which the students would participate. By working more closely with the high school administration prior to the start of the academic year this kind of scheduling could have been achieved.

Summary

For students entering college, picking a major is often a difficult choice. However for many fields of study, especially in the liberal arts, mathematics and the natural sciences, college study is an in-depth extension of the high school experience. Although most students expect a more in-depth and rigorous experience, a major in English, History, Mathematics or Chemistry is not an altogether foreign concept. However, most students do not have the chance to experience engineering at the high school level. That is why is it important to reach out to prospective students to bridge the gap between science and mathematics and engineering. By providing outreach research experiences that are rooted in a familiar science like chemistry but extend to traditional engineering subject matter, students can make a more informed decision with regard to a college major. Due to the success of this initial offering, plans are in place to offer additional high school outreach experiences in chemical engineering. For future offerings, high school administrators will work together with university personnel to develop a regular schedule, as well as an assessment mechanism for participating students.

Acknowledgements

Funding for this project is provided in part by the U.S. Environmental Protection Agency People, Prosperity and the Planet program, Funding Number SU834699. Special thanks are also given to: Owensboro Grain Company for support and guidance with regard to biodiesel production techniques and economic considerations; Dr. Charles Lu, Professor of Mechanical Engineering at the University of Kentucky Paducah Extended Campus and co-advisor for the P3 design team; Torey Earle, 4-H Agent at Large for Science, Engineering and Technology; and Lone Oak High School in Paducah, Kentucky. Their support with this project is gratefully acknowledged.

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