EFFECTIVE ENGINEERING OUTREACH
Through an Undergraduate Mentoring Team and Module Database

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According to the United States Bureau of Labor Statistics, the total demand for engineers is expected to grow by 11% between 2010 and 2020, with chemical engineering related fields expected to grow by 6%.[1] The number of bachelor's degrees awarded in engineering in the United States has grown by 18% since 2000, but chemical engineering degree totals have experienced a slight decrease in the same period, and, in 2009, the number of graduates was 6% below the 2000 totals.[2] As such, it is expected that the number of domestically trained chemical engineers will not be able to meet the demands of the expanding job field.

A significant hindrance to graduating sufficient numbers of engineers may be found at the K-12 level.[3-6] Many K-12 students lack fundamental knowledge of what an engineering career entails and the opportunities that are available to them as they enter college, making them less likely to consider engineering as a major.[5,6] Many students believe that science and math classes are not applicable to everyday life, with a common refrain being, "When am I ever going to use this again?" Without an understanding of how science and math are used to solve real-world, cutting-edge problems, students are less likely to pursue higher education in engineering fields.

Another barrier is that a disproportionate number of women and minority K-12 students cannot envision themselves as engineers due to gender politics, their perceived acumen for science and math, and a lack of visibility of people with similar backgrounds, among other reasons.[7-10] Between 2000 and 2010, the percentage of women earning their first degree in engineering declined from a high of 20.6% in 2002 to 18.2% in 2010. For underrepresented ethnic and racial minorities, the gap is even greater; only 12.6% of first degree earners were underrepresented minorities, although there has been a 0.5% increase since 2000.[11]

In response, many engineering colleges across the United States have developed K-12 outreach programs to proactively engage K-12 students and foster an interest in engineering related fields.[12-15] Professional organizations such as the American Institute of Chemical Engineers (AIChE) have also stepped up their K-12 outreach programs in response to this need.[16] Such programs use a variety of methods to engage students, including active learning through hands-on demonstrations, talks from engaging role models, service learning projects, and the development of online supplements to augment STEM instruction.[3] It is thought that by having students interact with practicing engineers, students will form a real-world connection to how engineering can apply to their lives and the paths that they could pursue to become an engineer. Despite the benefits of such programs, the most effective and sustainable means to conduct outreach programs indefinitely within an engineering department remain unclear.

In 2008, the National Science Foundation awarded a grant, entitled "Utah Engineers, a Statewide Initiative for Growth," to the College of Engineering at the University of Utah. Its purpose was to research effective and sustainable means of engineering outreach at the high school level to increase college enrollment and retention rates. Over its five years, this research project developed a robust, sustainable, and proven outreach program, utilizing and honing a wide range of outreach tools. A key component of this program is the training and maintenance of dedicated outreach teams of undergraduates.[17]

In this work, we describe how these teams were used to: 1) create and promote a dedicated community outreach presence; 2) develop an extensive online teaching module database;

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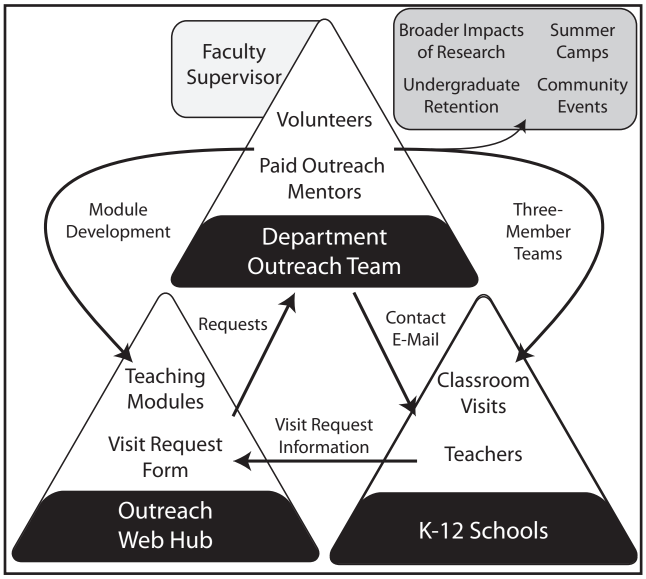

Figure 1. *Overview of our Outreach Model.*

and 3) organize and refine effective high school visits. The results of this program include a remarkable increase in K-12 student interactions, a high online visibility, and the creation of an efficient, sustainable culture of community outreach within our engineering department. Recent increases in interest, enrollment, and retention may be attributable in part to this program.

MATERIALS AND METHODS

Our outreach model is illustrated in Figure 1. This program is composed of three main components: trained student outreach teams, a strong online presence, and K-12 teachers.

Undergraduate outreach teams

Outreach efforts that rely upon donated time from student organizations, such as AIChE student chapters, are an important part of a department's outreach mission. However, outreach is not the prime function of such organizations, and they are necessarily limited in their scope by student and faculty availability. A critical component of this program's success was the development of a sustainable outreach team of knowledgeable and engaging students. This student group is made up of eight to 15 undergraduate chemical engineering students, dubbed "mentors," with nearly equal representation from freshman, sophomore, junior, and senior classes, to maintain continuity in training and a diversity of perspectives. In our experience, undergraduate students are able to engage K-12 students more naturally than faculty and counselors as they are in a similar cohort, and they are able to describe their recent experiences in applying to and attending college.

While several members volunteer their time, the majority of the mentors are paid between $10 to $14 an hour for time spent on outreach activities. Each year a new student leader is elected in the group, and a faculty member advises and organizes the outreach team at bi-weekly meetings. All volunteers are welcome into the group, but students wanting paid positions must apply. New paid mentors are selected by the existing mentor team during a recruiting process at the start of each semester, giving outreach members valuable experience in the interview and hiring process.

Applicants are asked to give a five-minute presentation, geared toward high school students, on the topic of "What is Chemical Engineering?" Successful applicants are selected for their passion about engineering, history of community service, and ability to communicate effectively with people of limited technical backgrounds. In our jurisdiction, we cannot consider underrepresented status as part of the hiring process; however, we have found that our pool of applicants tends to include a disproportionately high percentage of individuals from underrepresented groups, leading to a more diverse outreach team. At the end of the 2012-13 academic year, our outreach team consisted of 30% minority and 40% women mentors, whereas our general student population is composed of approximately 15% women and 15% minority students.

K-12 teachers and visits

Our outreach team has collected a contact list of local educators over the years and we are proactive in contacting local science and math high school teachers to solicit interest in the program, particularly during university holidays. After formal contact has been established, teachers use an online form[18] on our department website to select dates/times, class size, topics needed to make curricular connections, and demonstrations they feel would be most interesting to their class. Unsolicited requests typically occur at the end of the school year, when some teachers have completed their lesson plans.

Once a formal request has been received, one mentor is placed in charge of organizing the visit, with each mentor having a chance to lead visits. This gives mentors valuable organizational and leadership experience, which is important as they begin to apply for jobs and/or graduate school. The outreach member in charge of the visit must organize which mentors will attend the visit (typically two to four) and which teaching modules will be used. They also become the point of contact for the teacher who requested the visit.

Once in the classroom, the outreach team typically gives a 15-minute presentation that covers the basics of engineering and details the wide variety of fields and industries in which chemical engineers work. The end of the presentation focuses on the benefits of being an engineer, the skills that are required, and the university environment. The mentors then conduct a question-and-answer period. During this time, the mentors typically describe how to apply to college, how to apply for scholarships, the college experience, and how they became interested in engineering.

After the presentation, the mentors then perform the demonstrations and hands-on activities requested by the

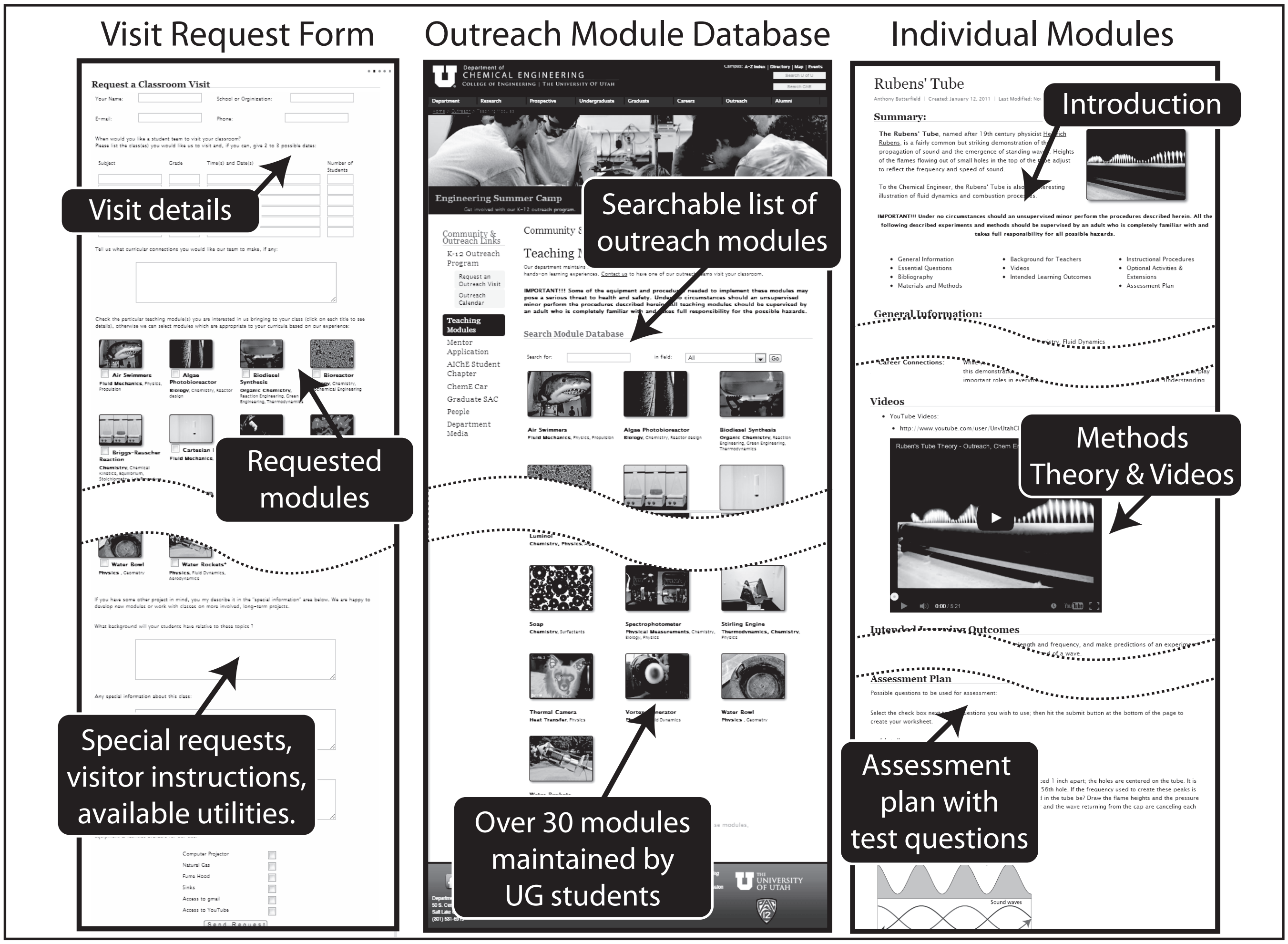

***Figure 2.** Online Outreach Web Hub. K-12 teachers use a visit request form to arrange visits and request modules from a module database. Each module has details to familiarize the teacher with the activity and aid him or her in incorporating it into their curriculum.*

classroom teacher and explain the relevant background and theory to the class. This is an excellent opportunity for both mentor and student, as by teaching, the mentor shores up their understanding of core chemical engineering concepts, and the K-12 student is exposed to science and engineering in a hands-on, active-learning setting that has been shown to pique interest and improve conceptual learning.[19, 20] The outreach modules have been designed to showcase core chemical engineering concepts, but also to be entertaining and demonstrate physical phenomena with which high school students may be unfamiliar. If requested, our team also provides the teacher with worksheets for his or her class involving the chemical engineering concepts presented.

In addition to single classroom visits, our outreach structure has opened up new avenues for in-depth K-12 involvement. Our outreach team has partnered with a local high school, The Academy for Math, Engineering, and Science (AMES), to teach a two-week course on chemical engineering. This course allows students to utilize principles of process design, bioengineering, and chemical reactions that introduce them to the cutting-edge problem of synthesizing alternative fuels, such as biodiesel. During this course, the students design and build a photobioreactor to grow blue-green algae and have a competition to determine which design allows for optimal growing conditions over a two-week period.[21] The students are also introduced to the production of biodiesel by performing a transesterification reaction using vegetable oil and sodium methoxide to create biodiesel and glycerol.[22] Throughout the entire two weeks, mentors take care to give students feedback and input on their design. Our team is now in the process of designing a four-week chemical engineering module for a pilot Introduction to Engineering course at another local high school. This course is intended to be effected statewide.

Outreach web hub and modules

One of the most important, lasting impacts of this project has been our development of chemical engineering teaching and outreach modules and the creation of an online database detailing each (Figure 2). Outreach modules and visit re-

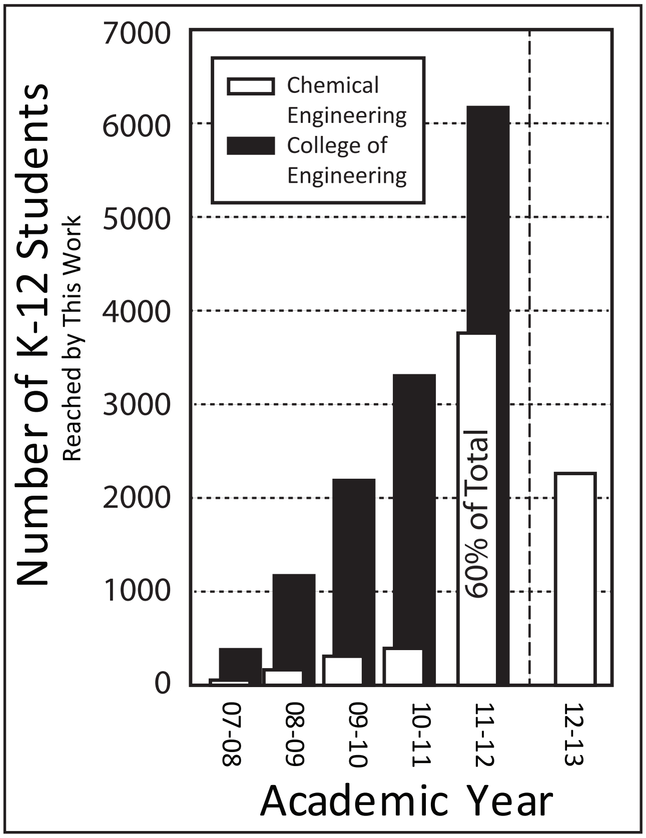

Figure 3. *Number of students directly contacted by this program.*

quest forms are displayed prominently on our department's homepage. These modules are primarily created by undergraduate mentors, with the aid of faculty, and are meant to demonstrate core chemical engineering concepts, such as heat transfer, reaction kinetics, mass transfer, separations, and fluid mechanics. The modules are designed for use in high school or college classrooms, with various levels of difficulty depending on the setting.

The online module database currently consists of more than 30 modules, which can be accessed from our department website (<http://www.che.utah.edu/outreach/teaching_modules>). This database was designed to help high school teachers and college professors design their own versions of our modules for use in their classrooms. Each module contains a complete list of the materials and methods, procedures, learning outcomes, career connections, and the relevant background and theory. The background and theory for the experiment is written at a level a high school student could understand, to help teachers explain important concepts in their classrooms. An important aspect of the background and theory is the ability to be scaled to various levels of difficulty for students in more- or less-advanced classes. While some modules are well-used staples of outreach, such as the Rubens' Tube,[23] they are tackled from a chemical engineering perspective. A variety of novel modules is also included, for example: building an inexpensive spectrophotometer,[24,25] the exploding can,[26] and the design and creation of an alginate bead production process.[27]

Each module also contains assessment questions that teachers can use as an assignment or quiz to test student understanding of the module presented. These questions have variable difficulty and can be printed as a worksheet from our website with or without answers. The final component of a module is an instructional video, which demonstrates the module and explains the important background and theory for students and teachers.

RESULTS

Each of the seven departments in our college of engineering was allotted an equal budget to develop an outreach program. Early in the work, our program's efficiency was on par with others (Figure 3), which all created some version of undergraduate outreach teams. Teams were selected by faculty, had little online presence, and took visit requests by phone and email. However, changing to the model described above, we were able to visit 3,818 K-12 students at more than 25 different schools during the academic year of 2011-12, up from approximately 30 students per year prior to program development. While the Chemical Engineering Department is among the smallest of the seven engineering departments participating in this outreach research, we were able to conduct approximately 60% of the College of Engineering's total outreach. Additionally, outreach students were not only in schools within close proximity to the university; our mentor team was the only one to establish an annual trip to rural areas to visit students who are rarely reached by large universities. The implementation of the model described herein over the 2010-11 academic year gave our team the capacity to contact more teachers and dramatically increase the number of students contacted through a combination of factors: active visit solicitation and accumulation of K-12 contacts at local schools; a prominent outreach presence on our department website; a clear and simple online visit request form; a wide selection of teaching modules; and a diverse, trained, and student-led team of outreach mentors.

In 2012-13, our goal was to trim back the outreach program to a level that could be supported by the department indefinitely, post-grant. Despite the budget being cut 60%, we only experienced a 40% drop in the total number of students reached, representing a 50% increase in the number of face-to-face visits per dollar spent. This efficiency was achieved largely by asking each teacher requesting a visit to ask others in the same school if they would have our teams in their classrooms on the same day. By doing so, we visited fewer schools, used fewer resources, but did not see a proportional drop in students contacted. Numbers are not shown for the College of Engineering in the 2012-13 year in Figure 3, as all other department outreach programs were consolidated into a single college program, which did not collect exact data. This college program estimates, though, that they visited 2,000 students, indicating our model is still responsible for over half of the college's classroom visits. Chemical Engineering was the only department to retain a dedicated and independent outreach program, in large part due to our successful implementation of the program described.

Similar interactions with K-12 students have been shown to increase interest in engineering-related fields.[28-31] By providing students with active-learning engineering experiences, they develop more positive associations with engineering in general. The primary focus of this work is to create an efficient means to maximize such interactions. Early in this program, we conducted surveys of students about the effect of outreach visits, finding results similarly positive to those in the literature and some constructive criticism used to improve our model. However, surveying students became a barrier to effective outreach, as it became a nuisance to students, teachers, and mentors. The practice was discontinued in 2010. Surveys are still conducted at our college summer camps, where more time is available. Generally, we measure a doubling of student interest in chemical engineering, from a pre-event level of approximately 10%. Such increases are an important first step in convincing students to pursue chemical engineering careers.

It is important to note that many factors, particularly economic factors, may affect college enrollment, and the direct impact of this program on enrollment and graduation rates cannot be clearly quantified. It is also difficult to measure the indirect consequence of any particular K-12 interaction, due to likely but untraceable inter-familial and inter-peer group influences originating from any one outreach event. Regardless, it is clear that the outreach model developed in this work is markedly effective at soliciting visits and reaching large numbers of K- 12 students efficiently (Figure 3).

While it's difficult to determine the exact impact of our outreach, enrollment in the College of Engineering is up 50% since the beginning of this program. Graduation rates in the college have also increased by approximately 100 students per year—one of the primary goals of the original grant. In the 2012-13 academic year, the chemical engineering class, most of whom entered college during the first two years of our outreach program, was the largest ever at the University of Utah, and we graduated more than 70 students, which is almost twice as many as the prior largest class. While the 2008-09 outreach totals are an order of magnitude lower than the totals reached between 2011-13 (Figure 3), they are still far greater than the numbers reached before this project began and at the start of this program. It also appears we are set to have our second-largest graduating class in the 2013-14 academic year, and at least one of our incoming graduate students is a former outreach mentor and former high school student directly reached by this program four years prior.

We surveyed the websites of 70 randomly selected chemical engineering programs in the United States and found that, while 72% of the departments appeared to be involved in some sort of outreach activity (using a Google search), only one (1.4%) of them had any sort of apparent outreach area on their website. Our work suggests a prominent outreach presence online is important to long-term success and carries with it several benefits. Our outreach web hub is a crucial means to attract local K-12 teachers and eases the process of requesting and tailoring an outreach visit, and our outreach hub also accounts for more than 30% of our department's total web traffic. The online teaching modules have been given very positive reviews from both professors and teachers worldwide who have told us that they have found the site to be very instructional and helpful. These online modules have also been utilized by professors within our department to incorporate hands-on activities into core courses and demonstrate important concepts in process control, fluid mechanics, combustion, and reaction kinetics classes.

Positive and unanticipated benefits of establishing this outreach program have been many and varied. While the student attrition rate in the department is near 40%, of the approximately 30 undergraduates involved in the outreach program, not one has left the department. Creation of strong social bonds to their department peers and an engineering identity is readily apparent in outreach team members. Although mentors are admittedly self-selected, which could account for part of their 100% retention,[17] creation of such social ties has also been found to have a strong positive effect on retention and likely plays an important role here.[3,4] Furthermore, because they repeatedly explain to K-12 students the benefits of their career path, these undergraduate mentors are uniquely clear on the reasons they themselves wish to be chemical engineers, which one might also connect to their 100% retention. Future work for our outreach team will focus on improving department retention in general.

Another benefit from this program is that, through the development of a consolidated outreach program, we now have a clear avenue by which our entire department may respond to opportunities that may have been tabled by busy faculty in the past. A dedicated outreach program has allowed us to take on many new events and maintain a presence at all campus and community events to which we are invited. Currently, this program facilitates two summer camps and conducts a portion of the state's Scientific Olympiad, furthering the visibility of chemical engineering as a viable and rewarding career opportunity. Lastly, this outreach model has found an important use within the department's research programs. The infrastructure built and maintained through this program is now a key component in disseminating the research conducted in the department throughout the community and addressing broader impacts within research proposals, such as those required by the National Science Foundation.

Due to the success and hard work of our outreach team, the Department of Chemical Engineering at the University of Utah has decided to continue funding the outreach program after the cessation of the NSF Grant, meaning outreach work will be able to continue uninterrupted for the foreseeable future.

CONCLUSION

We have demonstrated an efficient and sustainable community outreach program for chemical engineering departments. Through classroom visits, interacting with students, and community events, we have created a robust link for our department into the community at large. By educating K-12 students and exposing them to engineering, we increase the likelihood that they will consider engineering as a career, which is a critical first step in attracting more students to chemical engineering programs.

Through the creation of an online module database, we have constructed a tool that can be utilized by educators to develop chemical engineering demonstrations in their own classrooms, both at the high school and collegiate level. This database also serves as a centralized location to which teachers can refer when requesting the modules they think would serve their class best during outreach visits. The versatility of the database allows for continual updates as students develop new modules in the future. It is our goal that this database becomes a useful tool for engineering educators across the country.

Due to the success of our classroom visits and module development, we have fostered a culture dedicated to community outreach within our department, as shown by our department's commitment to continue to fund the program indefinitely. We believe this work will allow our department to reap the benefits of interacting with local students by drawing top-quality undergraduates to our program who previously may have never considered a career in chemical engineering.

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