Service and Design as Mechanisms to Impassion the Study of Engineering, from K-12 to Higher Education

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Abstract – Service and design provide mechanisms to introduce students to successive stages of engineering education. These activities positively influence outreach to K-12 students, recruitment of women and underrepresented minorities to engineering, retention of undergraduate engineering students, and encouragement and funding for graduate education. Furthermore, service and design provide continuity and motivation across engineering education. These offer experiential learning opportunities in practical problem solving while simultaneously promoting personal development of communication skills and team leadership. Strategies are discussed for implementing service and design components in engineering education at all levels from K-12 to graduate education. For K-12 outreach, a mentoring program called DREAM is highlighted. Opportunities for outreach and externally reviewed proposal writing and presentations are discussed in the context of undergraduate design. These can be implemented through both traditional course work and alternative design projects. Finally, the impact of all of the above activities on graduate education, particularly graduate funding, is discussed.

Index Terms – DREAM, graduate education, outreach, undergraduate education, underrepresentation

INTRODUCTION

The problem of underrepresentation of women and minority students in engineering education is positively impacted by coupling service with design projects in which physical prototypes are developed. This combination can be implemented effectively through both outreach programs and service learning projects. It is shown here that these two means of instruction are effective at each level of engineering education, from introducing K-12 students to engineering, to helping retain and diversify undergraduate engineers, and finally encouraging graduate study. At each educational stage, misconceptions on the part of the students must be dispelled. These range from K-12 students believing that college is not affordable, to undergraduates misunderstanding the means of funding graduate study. In addition to dispelling misconceptions, new skills must be developed in students at each stage to ensure their future success. The use of design and service to change perceptions and introduce new skill sets are discussed in this paper. When coupled, design and service offer means for continuity of purpose at all stages in engineering education, while simultaneously reinforcing leadership and communication skills. This paper is divided into three main sections: K-12 outreach, undergraduate education, and finally graduate education. In each section, the uses of various educational components of design are discussed,

and outcomes for the students are discussed. Each section concludes with a brief discussion of possible improvements.

Underrepresented Groups in Engineering Education

The need for increased engineering outreach to K-12 students has recently been documented by both the Oak Ridge Center for Advanced Studiesⁱ and the National Academiesⁱⁱ. In particular, underrepresentation continues to be a significant problem in engineering and other STEM (Science, Technology, Engineering and Mathematics) fields. Outreach programs that challenge perceptions and promote previously unconsidered career paths have the potential to introduce more underrepresented minority students to STEM fields, particularly engineering. Such programs provide role models which may eventually eliminate underrepresentation in these disciplines. As a practical motivation, targeted students may significantly improve their earning potential through successful completion of an engineering degree.

In 2006, the American Society for Engineering Education (ASEE) reported that only 11% of baccalaureate degrees in engineering were conferred upon representatives from African American and Hispanic or Latino groups combinedⁱⁱⁱ. The magnitude of this underrepresentation is made clear by the U.S. Census Bureau which reported that 12.3% of the U.S. population was African American and 12.5% was Hispanic or Latino in 2000^{iv}. However, there is also great opportunity to increase diversity in engineering, as 31% of the African American and 35% of the Hispanic populations are under 18 years of age^{v,vi}. Women are also largely underrepresented. ASEE reported that only 19.3% of engineering bachelor of science degrees were conferred upon women in 2006^{vii}. This represents the lowest percentage since 1998^{viii}. This highlights the need for increased outreach and mentoring of K-12 students from these groups to encourage them to pursue studies in engineering disciplines.

K-12 Student Impact

To address underrepresentation in engineering a mentoring program called DREAM has been developed. DREAM stands for Designing with Rice Engineers–Achievement through Mentorship. In this educational model, small teams of two to four high school students (mentees) and an undergraduate engineering student (mentor) collaborate to solve a hands-on, specified design challenge. This allows the high school mentees to apply concepts from physics and mathematics to hands-on projects and reinforce the scientific process. Instead of the dominate focus being on the technical design, mentorship is the primary goal. The service learning component in this model is the mentoring by the university students. Over approximately seven weeks, the teams create a solution to the design challenge, then test and iterate on their design solution before the final demonstration. Thus teams complete initial brainstorming, testing and refinement and finally prototype development components of the design process. This extended program also allows the mentee/mentor relationship to grow organically as the mentees observe the dedication of the mentors.

Undergraduate Student Impact

In addition to benefitting the mentees, DREAM also offers experiential learning opportunities for the mentors. Similar to programs such as EPICS^{viii} and SLICE^{ix}, the students involved in the DREAM program exhibit improved communication and leadership skills and enjoy a broader sense of purpose. As in these programs, undergraduate engineering students from underrepresented groups are disproportionately attracted to participate in DREAM, as discussed

below. DREAM mentors are volunteers and do not receive academic credit or compensation. Mentors exhibit both dedication and pride in the program, consistent with those studies that support volunteer service learning^{x, xi}.

Traditional undergraduate courses can also offer opportunities to impassion and reinforce the study of engineering, particularly in women and underrepresented minorities. One means of doing so is by incorporating projects which focus on outreach and service into design courses. These projects and programs have proven very effective for attracting women and underrepresented minorities to engineering. For example, women enroll in EPICS elective courses that have service-learning components at twice the rate of their overall representation in their respective engineering schools^{xii}. Similarly, women and non-Caucasian students rank “helping others” as the number two reason for wanting to enter engineering, while this motivation does not rank in the top four, on average, for Caucasian men^{xiii}. Specific projects with similar service learning components and their impacts are discussed in the section on capstone design. Alternative design projects outside typical engineering curricula, such as Rice’s home entry in the 2009 Solar Decathlon, also offer similar advantages.

Extension to Graduate Education

Service learning projects and courses also provide opportunities to introduce the idea of graduate engineering education to all students, including the large percentages of women and underrepresented minorities involved. Building skill sets such as applying for grants and presenting research provides the knowledge, experience and confidence needed when applying to graduate programs and for graduate funding. Other valuable activities include submitting proposals, publishing journal articles and conference papers, applying for patents, and presenting at conferences. These activities not only prepare students for graduate education, but provide experience and a foundation that often leads to success in obtaining significant graduate funding and the resulting recruitment into top graduate programs. These endeavors are especially important for underrepresented students as there is a tremendous deficiency of underrepresented minority role-models with advanced engineering degrees. Only 4.4 and 4.7 percent of master’s degrees in engineering were conferred on African-Americans and Hispanics, respectively, in 2006. In the same year, these groups comprised only 3.7 and 3 percent of doctoral degrees earned in engineering, respectively, and this low rate has remained steady for the last decadeⁱⁱⁱⁱ. Service learning projects and courses offer an excellent mechanism to alter these statistics.

While these various efforts may at first seem somewhat disjointed, collectively they offer an overview of several methods to incorporate service and design both through and outside of traditional learning settings. Even more important, the educational and career impacts that students can realize from these efforts are discussed. Overall, a systems level approach to transforming educational outcomes through service and design is presented, where the complete preparation of students involved is the system of interest.

K-12 OUTREACH

A significant challenge in engineering education is the recruitment and retention of underrepresented minority students. A multifaceted approach is required to overcome this challenge. A range of engineering outreach and mentoring programs have been developed at Rice University and implemented in conjunction with Houston area K-12 schools. Two of these programs, the DREAM program and efforts of the Rice chapter of the Society of Hispanic Professional

Engineers, will be discussed. These two programs share two common goals. The first goal is to provide underrepresented and socioeconomically disadvantaged K-12 students with a new perspective on engineering and demonstrate that achieving a degree in engineering is both possible and financially practical. The second goal is to prepare K-12 students for success in the college admission process. Significant positive outcomes for the undergraduate mentors and high school mentees involved in these outreach programs have been observed^{xiv, xv, xvi}.

DREAM Program

The DREAM (Designing with Rice Engineers – Achievement through Mentorship) program sends a team of Rice STEM undergraduates and graduates to mentor and teach students at three Houston high schools: Stephen F. Austin High School (AHS) and Cesar E. Chavez High School (CHS), both in the East End community, and KIPP Houston High School in southwest Houston. The goal is to encourage the high school students (mentees) to pursue college degrees in STEM fields. Mentoring relationships are formed naturally via small group design projects where mentors serve as project managers. Groups of two to five mentees meet with their mentor every week for 6 to 8 weeks each semester. Meetings take place in after-school sessions at AHS and KIPP and during scheduled classes at CHS. Teams test and iterate on designs leading up to a

Figure 1
A team of KIPP mentees races to construct their
launching
devices during the spring 2009 DREAM Day
competition.

demonstration which is held on the Rice University campus. The challenge is to perform some task and optimize the results. Tasks are based on some fundamental physics concepts. For example, challenges such as ping-pong ball launchers have allowed for demonstration of concepts such as the invariance of gravitational acceleration and ballistic flight. Another challenge focused on buoyancy and required the construction of a boat, which was loaded to the point of sinking. A fixed set of materials are supplied to the teams, with points awarded based

on a combination of efficiency (using the fewest supplies), construction (taking the least time to build) and performance of the tasks. Each of these areas are weighted differently, requiring the teams to optimize their solution. Other awards include most innovative design, most artistic design, and most reliable performance in a specific category (for example, triggering mechanism or stability). Teams are awarded graphing calculators, iPods, digital cameras and gift cards. The final competitions take place during DREAM Days at Rice University in both fall and spring, providing continuity to the mentoring relationship throughout the academic year. In addition to the competition, DREAM Days include tours of laboratories and design studios, and student panels where financial aid and college admissions are discussed. The long-term earning potential associated with engineering degrees is also highlighted.

The small team setting (2 to 3 mentees per mentor at AHS, and 3 to 4 mentees per mentor at CHS and KIPP) and high contact hours, with a goal of solving a design challenge, allows the mentoring relationship to form organically. Mentees grow to trust their mentor as they see the week-in, week-out commitment of every mentor, each volunteering their time freely. This increased trust has been observed in interviews with mentor focus groups and through increased response rates on personal questions posed to mentees through surveys. Most notably, the willingness of mentees to provide their parents' highest education levels, even though these are often very low, increases significantly over time^{xiv}. As each relationship forms, the mentees begin to inquire about more significant issues such as: why did the mentor choose to go to college, how does the mentor pay for college, what needs to be accomplished to prepare for college, etc. This allows the mentor to introduce the mentees to new perspectives and possibilities for the future. Few AHS and CHS students go to college in STEM fields and many choose to enter the workforce directly after graduation. KIPP students must gain admittance to a college or university to obtain their high school diplomas, but few study in STEM fields and almost none study engineering despite the excellent career opportunities. This is due in large part to not knowing about these fields or understanding what opportunities are available. This lack of understanding is not surprising given that the parents of most DREAM mentees did not have the opportunity to attend college. For example, a recent survey at AHS showed between a third and half of the mentees' parents have only a middle school or lower education^{xiv}.

Throughout the two year existence of DREAM over 95% of the mentees have been from

Figure 2

KIPP mentees test their launching devices during
the spring 2009 DREAM Day.

underrepresented minority groups and roughly reflect the populations of the schools served. In

the 2007-2008 academic year Austin High School had a student demographic of 96% Hispanic and 3% African American, with 90% receiving reduced-price or free lunch^{xvii}. In the same year, Chavez High School was comprised of 83% Hispanic and 12% African American students, with 81% receiving reduced-price or free lunch^{xviii}. All KIPP students are underserved. The KIPP campus has a student demographic of 79.6% Hispanic and 18% African American students and 87.5% are economically disadvantaged^{xix}. In spring 2009, the DREAM mentees from KIPP were comprised of 74% Hispanic and 15% African American students.

DREAM has seen steady growth in participation since its inception in fall 2007. The numbers presented here are only for “high participation rate” mentees and mentors who took part in at least 70% of the possible sessions. In the 2007-2008 academic year, DREAM at AHS served 25 mentees with 13 primary mentors, in either the fall or spring or both semesters. In fall 2008, 25 mentees were served by 25 mentors at AHS. DREAM has recently become more widely recognized in Houston and has appeared in both articles and news clips^{xx}. This promoted the expansion efforts, and in spring 2009 DREAM began at CHS and KIPP. Between the three schools, 96 mentees were served by 31 mentors in spring 2009. Throughout the 2008-2009 academic year, mentors had over 1000 contact hours with mentees at AHS. In spring 2009, mentors had 390 and 325 contact hours with mentees at CHS and KIPP, respectively. DREAM meets the six guidelines observed by the Oak Ridge Center for Advanced Studies (ORCAS) investigation of successful outreach programs, including beginning with an assessment that involving both students and teachers, building internal and external partnerships, incorporating college students in the outreach, regularly evaluating the program, securing funding and disseminating results.

Affiliated Service Programs

Mentoring and the eventual development of DREAM at AHS grew out of a tutoring collaboration with Rice's Society of Hispanic Professional Engineers (SHPE) and Stephen F. Austin High School. Recognizing a need for supplemental instruction and mentoring, the author and several Rice undergraduates created first a broad tutoring program, then the refocused DREAM program. The goals of these efforts were to encourage students to pursue their interests in science, engineering, mathematics and analytical problem solving. The tutoring program started in 2006. In its first year of existence (2006-2007), the program was predominantly focused on aiding students with homework and science fair projects. From the fall of 2006 to the spring of 2007, Rice students volunteered over 100 hours at AHS. In the science fair, two supported students placed first in their respective categories (engineering and environmental science) at AHS, and one of those placed first in the Houston Independent School District (HISD) East Regional.

During this same period, the author began mentoring an AHS junior, providing specific advice related to college planning. By chance, the student happened to be interested in studying mechanical engineering. A quick review of his schedule showed that he was not planning to take calculus in his senior year because it was not required to graduate. This oversight would have significantly diminished his application to an engineering degree program. Even if he was accepted, he would have started his studies underprepared. Fortunately this oversight was avoided, and the student recently completed his first year mechanical engineering curriculum at a well-respected and highly ranked university. While anecdotally important, this case also highlighted the significance of adding a mentoring component to more traditional tutoring initiatives, and during the summer of 2007 the DREAM program was created.

Existing and ongoing programs with AHS include the Rice-Austin College Expo RACE to an Engineering Career Day. This SHPE initiative, started in 2006, brings 30 to 40 AHS students to Rice University one day each semester. Similar to DREAM Day, the high school students hear

Figure 4
An AHS student tests her team's roller coaster at RACE
Day in spring 2007

talks from professors and undergraduate students, discuss financial aid and admissions, and tour laboratories and design studios. At the end of the day, they participate in a hands-on roller coaster design and competition. GEAR-Up Day is a similar program that SHPE hosts once per year for students from Pasadena Independent School District.

Mentee Outcomes

All of the programs discussed above attempt to introduce underrepresented high school students to opportunities that they often feel are beyond their reach. Several myths tend to dissuade these students from seeking college degrees, particularly degrees in engineering. Many underserved students hold to the common myths that college is too expensive and that they are poorly

prepared to succeed in college. Many simply don't know how to go about applying to college or for financial aid because their families have no college experience. The process often seems overwhelmingly difficult. DREAM and RACE Day provide mechanisms to dispel these myths and encourage high school students to weigh the opportunity costs associated with entering the workforce immediately after high school, as compared to obtaining a college degree in a STEM field, particularly engineering.

DREAM offers a way to introduce engineering as an exciting field, through team design and competition. Furthermore, the consistent participation allows true mentoring relationships to form between the high school mentees and mentors. That mentors volunteer their time freely is a point not lost on the mentees and this helps build trust in the relationships. Often a significant shift is observed on or around the third meeting, when mentees start to open up to their mentors and ask important questions about college life and studies.

DREAM is a data driven program. The data collection can be divided into two categories: "perceptions and environment" and "content knowledge." The former is collected from Perception and Environment Surveys (P.E.S.) and the latter from Inventories (Intuition Inventories and Physics Concepts Inventories). The P.E.S. have shown that DREAM is effective for introducing fundamental aspects of engineering. Mentees responses at AHS to the question "What do you think an engineer does?" were evaluated over a three semester cycle (September 2007 to November 2008). Responses were graded on a five point Likert scale, and results are shown in Figure 5. Note that the initial September 2007 data indicates that DREAM mentees are often more serious students and tend to respond more thoroughly to the P.E.S. compared to the control group, where 20.4% did not answer this particular question. This is not entirely surprising as mentees at AHS essentially self-select to participate in the program, which is after school and entirely voluntary. Approximately 100 mentees are invited by letter. Others are recommended by their teachers. However most self-enroll or are recruited by friends. Each semester the 25 to 40 AHS mentees are made up of a mix of these recruitment strategies. Note that mentee responses scored "Good" and "Exceptional" increased from a total of 20.7% to 44.4% over the three cycle period. In comparison, only 2.5% of the control group scored at these levels.

The P.E.S. data also shows interesting trends in mentee understanding of financial aid. At or near 100% of mentees at AHS indicated that they plan to attend college in every instance that the P.E.S. has been administered over two years. Mentees are then asked how they plan to pay for college, and allowed to circle any or all of the following choices that apply: “parent(s)/guardian(s)”, “scholarships”, “loans”, “work study/part time job”, and “don’t know”. Most interestingly, no AHS mentees have answered “loans” alone. This suggests a negative and

Figure 5

Responses to the P.E.S. question “What do you think an engineer does?” from AHS students. All data other than the control are from DREAM mentees. misinformed association with the idea of loans. Therefore, DREAM mentors have recently initiated conversations about the value of borrowing a small amount in student loans to later secure a more profitable and rewarding career. More emphasis has been placed on what levels of financial aid mentees can expect. Spring 2009 survey data indicates early impact from this effort, in that a significantly increased percentage of mentees can identify that they have at least heard of the FAFSA, whereas in previous semesters no significant gains were observed in this metric.

Inventories measure physical intuition (Intuition Inventories - I.I.) and the ability to use mathematical representations in physics problems (Physics Concepts Inventories - P.C.I.). For example, in many of the design challenges the primary source of energy is gravitational potential energy. Questions on related I.I.’s focus on topics, such as the invariance of gravitational acceleration and decomposition of vertical and horizontal motion, while P.C.I.’s explore concepts of kinetic and potential energy. Significant gains are observed in mentee responses before and after DREAM. On both the I.I. and P.C.I., the percentage of correct responses to the primary question increases typically by 40% or more. This indicates the ability to use design to

teach physics in an engaging and meaningful way.

One final important finding was that the makeup of mentees included a much higher percentage of girls than would be expected based on the graduation rates of undergraduate women in engineering. At the two schools (AHS and KIPP) where the participants essentially self-select, between 45% and 48% of the mentees are girls, on average. This indicates that girls may find design, teamwork, problem solving or all of the above to be attractive components of engineering. This is promising as these aspects are very accurate representations of “real-world” engineering. Future studies will track the long-term participation of female mentees to determine their retention rates in the program.

Among the most significant outcomes: in fall 2009 seven of eight seniors that were long-time DREAM mentees at AHS indicated a desire to study engineering in college. This interest is attributable solely to DREAM, as there is no pre-engineering curriculum at AHS, and nearly all mentees will be first generation college students. Mentors helped prepare these mentees for college admissions through counseling on applications and encouraged mentees to take standardized entrance exams. All eight AHS seniors have received acceptance into one or more universities, with five still planning to major in engineering or science.

More details about DREAM, including samples of the P.E.S. and Inventories and the associated data analyses can be found in three recent publications^{xiv, xv, xvi}. Also included the rules and scoring criteria for two of the DREAM design challenges.

Mentor Outcomes

DREAM follows the trend of other service learning and outreach oriented programs in that women and underrepresented minorities are disproportionately attracted to serving as mentors. For example, in 2008 the Rice George R. Brown School of Engineering included 6% African American and 12% Hispanic undergraduate students. Figure 6 shows however that students from these groups made up approximately 13% and 39% of the mentors, respectively,

Figure 6
Demographics of the 31 high participation rate mentors from the
Spring 2009 DREAM program.

accounting for more than half of the mentors despite comprising less than 1/5 of the undergraduate engineering population. Also, women accounted for more than 32% of the mentors.

DREAM provides significant outcomes to the mentors, both tangible and intangible. As project leaders, mentors must improve their communication, management and organizational skills to create effective teams. Many also indicate that mentoring is not only rewarding service, but is also enjoyable. Mentor fulfillment is consistent with the fact that most mentors return to the program, semester to semester. For example, 80% of the 25 fall 2008 mentors returned in spring 2009. Of those who did not return, three undertook roles with tremendous time commitments, including two who became presidents of engineering societies.

Mentors also see tangible outcomes from their participation in DREAM. Mentors who exhibit the most leadership are invited to publish and present their work and assist in grant writing. In particular, three undergraduate mentors were coauthors on a conference paper and presentation at the 2009 American Society for Engineering Education (ASEE) Annual Conference^{xiv}. Four undergraduates and one graduate student coauthored two additional papers in the 2010 ASEE Annual Conference Proceedings, and two of these presented the findings^{xv, xvi}. Two poster were presented at the 2009 Sigma Xi Annual Conference, with contributions from seven undergraduates and one recent graduate^{xxi, xxii}. Additionally, DREAM mentors have received external funding to enhance the program, including funding to participate in the workshop “Engineer-in-Training for High School Students: An Out-of-School Exposure and Inspiration Experience,” sponsored by Sigma Xi in collaboration with the Shodor Education Foundation. One head mentor, who also served as the 2009-2010 academic year president of the Rice chapter of the American Society of Mechanical Engineers, wrote and received a Diversity Action Grant from ASME for DREAM.

The two students who co-founded DREAM each received the Alan Grob Prize, which is awarded annually to approximately five Rice undergraduates who, through service to the larger Houston community, have demonstrated devotion to the needs and interests of the economically and culturally disadvantaged and exemplify the values of community service. One was also awarded the Houston Mayoral “Volunteer Houston” Award, which honors approximately 15 individuals who do remarkable volunteer work in the Houston area. Recently undergraduate three head mentors who have all published findings related to DREAM were awarded ABS scholarships. ABS award criteria equally weight academics, service and external dissemination of research findings. Such externally reviewed publications, presentations, proposals and awards are viewed very favorably by both employers and graduate programs. Several of the former DREAM mentors have been honored with fellowships that require, in part, a demonstrated commitment to service. These examples are discussed in the section “Graduate Recruiting and Preparation.”

Future Enhancements in K-12 Outreach and Mentoring Experiences

Several efforts to improve the effectiveness of K-12 outreach will be initiated in the coming semesters of the DREAM program. In fall 2009, senior mentees will be given additional direct assistance with their college and financial aid applications. Long-term success will be measured by acceptance rates of DREAM mentees into STEM degree programs. Furthermore, retention and success in degree completion will be monitored.

Future efforts will place mentees in research laboratories and design teams with undergraduates and graduate student advisors. This will help provide the mentees a realistic view of engineering education and research. The long-term visions is to train 11th and 12th graders who

have previously participated in DREAM as mentees to become mentors for middle school students. This will broaden the impact to the crucial middle school years when many underserved students slip through the educational cracks. It will also address the scalability of DREAM and improve its sustainability.

Finally, in fall 2009 increased focus will be placed on improving undergraduate and graduate understanding of the outcomes of their own mentoring experiences. Self-evaluation and reflection surveys will be used to help mentors better understand their own motivations for serving and to reinforce long-term commitments to outreach.

UNDERGRADUATE DESIGN EDUCATION WITH EXTERNAL EVALUATION

Integrating outreach and service learning into design is effective for the retention of women and underrepresented students in engineering at the undergraduate level. While the implementation ideally extends across the curriculum such as in the EPICS program^{viii}, effective service learning projects can also be readily introduced in either traditional curricula or through alternative design projects. Examples of traditional capstone design efforts presented here include the senior design teams that developed the Adaptive WaTER Laboratory and a scaled-up water treatment system. An example of a nontraditional effort is the Rice Solar Decathlon project which designed and built the Zero Energy Row (ZeRow) House. Each of these projects included service learning components and involved several forms of external evaluations including proposals, presentations, and publications. As in DREAM, undergraduates were encouraged to take a prominent role in applying for funding and presenting and publishing their work. These components can be implemented effectively as either a course requirement or an independent objective of the project. In either implementation, it is important to explain the reasoning and benefits to the students involved, as the potential outcomes are rarely transparent to undergraduate students. Externally evaluated components are typical requirements at some stage of graduate education. Incorporating these components inspires students to pursue advanced degrees while providing them the necessary experience and confidence to do so.

Service Projects Within Traditional Curricula

Leadership and communication can be greatly enhanced through service learning projects, including those integrated into traditional coursework. Two recent capstone design teams developed first an educational water purification laboratory, the Adaptive WaTER (Water Treatment for Education and Research) Lab, and then a scaled-up system for water purification in developing nations. The Adaptive WaTER Lab consists of six housings, one each for sediment filtration, carbon filtration, reverse osmosis, forward osmosis, chemical sterilization and ultraviolet sterilization. This system, combined with water testing kits, is used to teach K-12 students about the various mechanisms for water treatment. After designing and fabricating the Lab, the capstone design team demonstrated the lab to over 300 underserved and underrepresented students in the Houston area. The schools served included AHS, Klein Middle School, Alief Middle School, and Cornelius Elementary, which have populations of 80% to 99% underrepresented students^{xvii, xxiii, xxiv, xxv}. Further details and specifications of the WaTER Lab can be found in Beach *et al.*^{xxvi}. Here the secondary outcomes (the successful completion of their capstone coursework being the primary) for the undergraduates are of most interest.

The initial team was inspired to propose a scaled-up water purification project for schools and clinics in developing nations. The team realized that the Adaptive WaTER Lab could be used to teach the importance of sanitation and water quality in conjunction with water related

Figure 7

Three UNIV capstone design students (right) guide hands-on demonstrations of the Adaptive WaTER Lab to K-12 students at the EPA P3: People, Prosperity and the Planet Expo in Washington, D.C. in April 2008.

service learning implementation projects. The team of five undergraduates was awarded an EPA P3: People, Prosperity and the Planet phase I research grant^{xxvii}. In addition, the team submitted a patent on the WaTER Lab. The goal of the patent is to sell the Adaptive WaTER Lab in the U.S. at twice the cost of production. The profit from the sale of each unit will go toward a donated Lab for a school in a developing country.

The team also published and presented their findings. The entire team was named on a paper that describes the technical details and initial educational impact of the Lab^{xxviii}. Additional educational outcomes of the Lab were published and presented by one of the students who continued in graduate studies and used the Lab for outreach to underrepresented high school students^{xxviii}. This ASEE conference paper, was awarded the Environmental Division's Early Career Paper Award. The Lab was also used for an undergraduate teaching module and one student inventor was named on the associated conference paper^{xxix}.

The second team carried out the scale-up design proposed in the EPA grant in the 2007-2008 academic year. The resulting system consisted of a slow sand bio-filter (Biosand) in a concrete shell, with an ultraviolet sterilization finishing tank, powered by a solar array. Significant improvements to the Biosand filter were achieved in terms of sustainability. A lightweight, reusable pvc mold was developed. The filter shell was designed with a passageway formed into the wall, eliminating the need for additional piping which can be expensive and difficult to procure in remote locations. The result was a Biosand filter design that requires the local procurement of only concrete, coarse rock and sand. This makes it a good option for production and distribution to individual residences in rural areas of developing nations. The ultraviolet finishing tank was designed for use where absolutely sterile water is critical, such as in clinics or

schools. While not sustainable, it can accommodate higher flow rates making it a practical solution for locations with larger gatherings. This team prepared a successful proposal to BP for the donation of two solar arrays. They also received funding from Van Drunen Farms for fabrication of the stainless steel finishing/holding tank.

Results from the project were disseminated in several ways beyond the presentations and reports required of the capstone design course. The 2007-2008 team presented their work and gave hands-on demonstrations of the WaTER Lab at the EPA P3: People, Prosperity and the Planet Design Expo in Washington, D.C. in April 2008^{xxvii} as shown in Figure 7. They also wrote a phase II EPA proposal. Finally, their design report was shared with the nonprofit group Health Empowering Humanity (HEH) for possible implementation in a new clinic in a rural community in Haiti.

Eleven students comprised the two teams discussed above. Of these eleven, four were women and two were underrepresented minority students. Seven of the eleven, including all four of the women, are seeking advanced degrees (six in engineering, one in law). Four seeking advanced degrees in engineering have been awarded prestigious fellowships or scholarships, as will be discussed in the following section. Three of these four participated in outreach at Austin High School.

Service Projects Outside Traditional Curricula

Projects independent of traditional curricula and cutting across many fields and disciplines also offer opportunities for undergraduates to gain experience with the external review process. The ZeRow House (Zero Energy Row House) is Rice's entry into the 2009 DOE Solar Decathlon competition^{xxx, xxxi}. An undergraduate civil and environmental engineering student and a graduate architecture student were the primary authors of the initial proposal, which was awarded one of

Figure 8
Members of the ZeRow House Solar Decathlon team install the front window.

the DOE's \$100,000 grants. Through this project Rice students have designed an 800 square foot house that is powered in net by solar arrays mounted on the roof. The house is designed to be grid-tied, so that extra power generated during the day can be sold back to the grid and will more than offset power consumption at night. This eliminates the need for storage batteries, improving the sustainability of the house. Since its inception, the ZeRow House has been designed for donation to the organization Project Row Houses, which provides housing for low-income families in Houston's Third Ward^{xxxii}. To be reproducible for use in this setting, the house had to be reasonably priced. Therefore, from the beginning, students decided to sacrifice costly elements typical of homes that historically win the Solar Decathlon, in favor of a much more affordable home. The home was constructed during the 2008-2009 academic year at Rice University, predominately by students, under the guidance of university faculty and outside engineering design firms, and the help of apprentice unions. Several special topics courses were run during the two year project. These typically included a lecture component, where fundamentals of the electro-mechanical systems or energy balances were discussed, and a practicum component, which involved actual design and construction of the house. Overall more than 100 students from all major disciplines (science, engineering, architecture and humanities) were involved over the duration.

In addition to the original proposal, the undergraduates working on the ZeRow House have been or will soon be exposed to many additional externally evaluated components. A successful faculty initiative grant was proposed to Rice, and reviewed by the American Association for the Advancement of Science. This grant helped support the work of student designers during breaks throughout the academic year. The recently completed house was viewed by many external individuals and firms during the 2009 Rice Design Alliance tour. In October 2009, the house will be displayed on the National Mall in Washington, D.C. where it will be toured by thousands of individuals and evaluated by a panel of expert judges. After the competition, the house will be delivered to the Project Row Houses community in Houston.

One of the original proposal authors, now entering graduate studies in civil and environmental engineering, is currently collecting data on the power production capabilities of the house and the efficiencies of various systems such as the solar hot water heater. These results and additional details of the house design will appear in a future manuscript and were presented at the 2009 Sigma Xi Annual Conference^{xxxiii}.

The outcomes from both capstone design projects and the Solar Decathlon project are summarized in Table I. Independent of the mechanism, these experiences promote confidence and awareness of opportunities available in graduate studies. They also provide an occasion to teach skills important for success in graduate applications and research, motivated by the service learning attributes of the project.

Future Enhancements in Design Education, Service and Dissemination of Findings

The externally evaluated aspects of the highlighted design projects have aided many of the student participants who have or are continuing on to graduate school. These outcomes are discussed in the following section. Future work will attempt broaden undergraduate participation in externally evaluated proposals, presentation and publications. The Solar Decathlon project serves as an example of how this can be done. This was a student initiated project at Rice, motivated by combined passions for environmental research and service to the Houston community. The students were empowered to follow through on their passions by the support of a few faculty members. Furthermore, while students wrote more than 90% of the

original DOE proposal, faculty experience and guidance was crucial to the successful outcome. In this way, many other student initiatives can be carried out with high impact to the students, the populations served, and the audiences of researchers and other students developing their own programs. The impact on undergraduate knowledge of these processes will be evaluated and the impact on students continuing on to graduate studies will be measured.

Table I

SUMMARY OF IMPLEMENTATION AND EXTERNALLY REVIEWED ASPECTS OF DESIGN PROJECTS.

Project:		Design and Prototyping of the Adaptive WaTER Lab	Scaled-up Water Purification System for Schools and Clinics in Developing Nations	Solar Decathlon ZeRow House
Academic Year		2006-2007	2007-2008	2006-present
Project Implementation		traditional capstone design course	traditional capstone design course	independent topics courses in engineering and architecture
Students Impacted		5 mechanical engineering	4 mechanical, 1 electrical and 1 civil and environmental engineering	> 100 across engineering and architecture; additional from science, humanities
Student Outcomes	Grant Proposals	· EPA P3: People, Prosperity and the Planet phase I	· BP Solar panels · Van Drunen Farms (stainless steel tank) · EPA P3 phase II (honorable mention)	· DOE Solar Decathlon grant · Rice Faculty Initiative grant · Shell Center for Sustainability grant
	Presentations	· ASEE “Adaptive WaTER Laboratory for K-12 outreach on sustainable water use” (Pittsburgh, PA)	· EPA P3 Expo (Washington, D.C.)	· Rice Design Alliance tours · DOE 2009 Solar Decathlon (Washington, D.C.) · 2009 Sigma Xi Conference (Woodlands, TX)
	Publications and Patents	· IJSLE journal paperxxvi · ASEE conference paperxxviii · ASME conference paperxxix · U.S. utility patent (pending)	· report detailing a design for the Health Empowering Humanity clinic	· journal paper in preparation for fall 2011 submission

GRADUATE RECRUITING AND PREPARATION

Service and outreach offer excellent experiences for undergraduates continuing to graduate studies. In addition to enhancing leadership and communication skills, a history of service significantly improves the chance for undergraduates to secure independent graduate funding. Students who have published and presented externally reviewed work are more desirable to graduate programs and advisors. A very high percentage of graduates who worked in one or more of the above mentioned programs have continued on to graduate or professional school.

Fifteen engineering undergraduate DREAM mentors have graduated since the inception of

the program, as of spring 2010. Seven of these mentors are in advanced engineering degree programs, three seeking Ph.D.'s. Three others are in professional degree programs (one medical student, one law student and one public health student). Combined, this accounts for more than 60% of the DREAM mentors who have graduated. Furthermore, of the ten former mentors seeking advanced degrees, five are women and four are underrepresented minority students (three of which are women). An additional student involved in volunteer tutoring at AHS is also seeking a Ph.D. in engineering.

Similarly, of the eleven students who worked on design projects related to the Adaptive WaTER Lab and the scaled-up system, four are currently pursuing Ph.D.'s in engineering, two are pursuing M.S. degrees in engineering (one through the prestigious GE Edison program) and one is preparing to enter law school, again accounting for more than 60% of the students involved. Note that two of these Ph.D. students, one M.S. student and the law student also previously served as DREAM mentors and one Ph.D. student was a tutor at AHS.

These statistics support the hypothesis that students who participate in outreach, service learning and some form of external review are more likely to have the confidence to apply and the skill set to be accepted to graduate or professional school. As another example, the primary undergraduate author of the Solar Decathlon proposal is also completing an MS in engineering. The subset of the above mentioned students who are seeking advanced degrees are summarized in Table II. Note that only one female student is entering graduate school with the intent to complete a PhD.

TABLE II
UNDERGRADUATE CONTRIBUTIONS TO EXTERNALLY EVALUATED COMPONENTS OF OUTREACH PROGRAMS OR SERVICE LEARNING PROJECTS. CONTRIBUTIONS COMPLETED OR AWARDS GRANTED IN GRADUATE SCHOOL BUT BASED ON WORK DONE AS AN UNDERGRADUATE ARE MARKED +.

student	gender	(or volunteer tutor*)DREAM mentor	proposal	conference poster	conference paper	journal paper	highest degree sought	fellowships, scholarships or awards
S1	F	Y	Y	Y	Y		PhD	CD Broad Fellowship, NSF
S2	M	Y *	Y		Y +	Y	PhD	NSF +, NDSEG +
S3	M	Y	Y +	Y +	Y +		MME	Mayor's Award, Alan Grob
S4	M	Y	Y	Y			PhD	NSF Honor. Mention, NSF +
S5	F	Y	Y	Y			MS	Wagoner Foreign Study
S6	F	Y	Y	Y			Law	

S7	F	Y		Y	Y		MS	
S8	M		Y	Y			PhD	
S9	F	Y			Y		MPH	Alan Grob
S10	F		Y			Y	MS	GE Edison Program
S11	M		Y	Y ⁺		Y [*]	MS	Outstanding Senior
S11	M	Y					PhD	
S12	M	Y					MD	

While a small sample set, this still raises the issue of confidence in men versus women. While participation in mentoring, outreach and external dissemination appears to increase undergraduate student confidence, it may not increase it as much in women as in men. Note that + markers in Table II indicate contributions that were completed in graduate school based on outreach and service performed when students were undergraduates and therefore these aspects could not contribute to an initial desire to pursue a graduate degree. The * indicates a journal paper in preparation.

Also listed in Table II are significant awards, fellowships and scholarships awarded to the students based at least in part on their service as mentors or their contributions to externally disseminated findings. Two students were awarded travel fellowships. One received the C.D. Broad Fellowship for a year of study at Cambridge and a second a Wagoner Foreign Study Scholarship for study in the Water Resources and Environmental Engineering department at the National Technical University of Athens. The two student co-founders of DREAM were awarded the Alan Grob Prize for service to the economically and culturally disadvantaged in Houston.

Extension to Graduate Funding

Experience with writing proposals and disseminating findings provides a great advantage when undergraduates apply for admission to graduate school and for graduate fellowships. The benefits are two-fold. First, graduate admissions committees and grant review panels are able to see a track-record of dissemination, or at least have confidence that the student understands the value of dissemination. Second, the student gains a better understanding of the review process and the importance of the point of view of the evaluators or program managers. An otherwise good proposal will not be awarded if the connections to the RFP are not transparent.

As shown in Table II, many students involved in the activities discussed have also received significant and prestigious graduate fellowships. In particular, three students involved in outreach to AHS have received NSF Graduate Research Fellowships (one first received an honorable mention). In all three cases, reviewers cited their sustained outreach efforts in evaluating the broader impacts of their proposals. One AHS volunteer tutor also received a National Defense Science and Engineering Graduate (NDSEG) Fellowship. The previous grant writing experiences and efforts to disseminate their work were significant factors in the success of these proposals. Finally, two other students who made significant contributions as undergraduates are now earning Master's degrees in programs sponsored by their respective employers.

Future Enhancements in Preparing Students for Graduate Education

While DREAM has successfully bridged K-12 and undergraduate education, and service learning design projects provide a link between undergraduate education and advanced degrees, it is desirable to both enhance these connections and make a direct link from graduate school to K-12 outreach. To address the enhancement of K-12 to undergraduate collaborations, future design projects will include high school students as team members. They will join their teams for regular meetings via web conferences and also meet occasionally in person. Furthermore, efforts will be made to include high school students in graduate research labs and to recruit graduate students as mentors for DREAM. This will make both undergraduate and graduate studies more tangible for K-12 students. It will also benefit the graduate students to supervise K-12 students, better preparing them for running their own research laboratories.

Finally, it has been observed that there is a connection between service learning, mentoring and outreach and the desire to pursue advanced graduate studies. However, it is not clear if this is a causal relationship. The perceptions and family backgrounds of students involved in DREAM and other service learning projects will be studied through surveys and self-reflections. With before and after data, it will be possible to determine if women and men are impacted in the same or different ways by serving others. The roles of family education levels and advising will be studied, allowing for the evaluation of the completeness of students and their own understanding of the opportunities available. Correlations to the desire and confidence to pursue graduate education will be sought.

CONCLUSIONS

Service coupled to design provides successful motivation for engineering studies. These mechanisms are effective at all levels, from outreach to K-12 students, through undergraduate recruitment and retention, to preparation for graduate education. Examples at each of these stages are presented, with many having complementary inputs and outcomes. Women and underrepresented students are preferentially attracted to service and service learning. In all cases, undergraduates are encouraged to participate in externally reviewed activities including preparing grant proposal and disseminating findings.

DREAM is an effective outreach program that encourages K-12 students to consider engineering as a career path. Earning potential is discussed as motivation for completing a degree in engineering versus entering the workforce immediately after high school. Data indicates that DREAM mentees have a better understanding of what engineers do. They also know more about college admissions and financial aid. Furthermore, DREAM is effective at teaching physics. On the primary questions on Intuition Inventories and Physics Concepts Inventories, scores increase by 40% on average from the beginning to the end of each cycle of DREAM. Mentors not only find personal satisfaction but also enhance their communication and leadership abilities.

Service learning can be successfully integrated into existing coursework such as capstone design, or introduced through nontraditional projects like the Solar Decathlon. Undergraduates are motivated by the service learning aspects as they are able to contribute to the greater good in a meaningful and tangible way. Such projects offer many opportunities to apply for funding and disseminate findings through papers and presentations. These experiences better prepare undergraduates for both industry careers and the pursuit of advanced degrees. Significant improvements in student communication skills and confidence are observed.

Finally, undergraduates who demonstrate commitments to outreach and service and also disseminate their work greatly increase their chances for acceptance into top graduate programs

and for acquiring prestigious fellowships. Combined with experience in grant writing, these students have the confidence and ability to prepare successful proposals.

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